United States Naval Postgraduate School

THESIS

COMPUTERIZED SURVIVOR SEARCH PLANNING

by

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ABSTRACT

A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.

An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.

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I. INTRODUCTION

A. THE COAST GUARD AND SURVIVOR SEARCH

Survivor search is defined as the process of planning and executing a search for survivors at sea, and the Coast Guard usually accomplishes this in the following steps:

1. <u>Initial Notification</u>

This stage involves gathering all available data about persons or craft in distress, including characteristics of the survivor craft, number of survivors, etc.

2. <u>Initial Distress Position</u>

In this stage, the search planner puts together all the available data concerning the survivor and makes a judgement as to what the most likely position of the survivor was at the time the craft seased operating normally.

3. <u>Drift Calculations</u>

The survivor's suspected motion is plotted assuming drift in the open ocean, and a position is calculated for some future time, usually the planned beginning of search efforts.

4. <u>Calculation of the Area to be Searched</u>

An estimate is made of the accuracy of the survivor's position as calculated in step 3 and the accuracy of navigation of the search craft. An area, called the

Search Area, is defined based on these errors.

5. Allocation of Search Units

A determination is made of the resources (ships, planes, boats, etc.) to be used in the search, and the way in which these resources will be used.

6. Execution of the Search

Searching is accomplished according to several established search patterns, most of which are different arrangements of a series of parallel paths within the Search Area.

7. Termination of the Search

Either the survivors are located or, after a certain amount of searching is completed without success, the search is terminated. This stage includes reports, and the evaluation of search effort.

B. DOCTRINE

The guidance for all these activities is contained in Coast Guard publication CG-308, the National Search and Rescue Manual, (Ref. 1.). Chapters 3 through 8 of this manual contain the instructions for planning and conducting a search for survivors at sea.

C. PURPOSE

This thesis accomplishes two things:

1. Provides a computerized solution to step 3 of the search planning process, calculating survivor craft drift, and

2. Investigates the criteria used for allocation of resources to a search, steps 4, 5, and 6.

It is intended that the results be understood by the search planner, so that they may be of some use to him.

II. THE SEARCH PLANNING PROGRAM

A. OBJECTIVE

The major objective in designing a computer program for search planning was to have a fast, accurate means of obtaining an estimate of a survivor's oceanic position at the time of the beginning of a search.

B. THE MANUAL METHOD

In order to understand the program, it is first necessary to understand how drift plotting is done manually.

1. Example

A fishing vessel is believed to have sunk at latitude 40-42.0N, and longitude 52-13.0W, at 0900z on 22 June. The probable error of this position is estimated to be 30 miles. Although the standard measure of variability is the standard deviation, all error estimates made in the search planning process are in terms of probable error. It will be demonstrated that this error is defined by the statistical term, "probable error". Survivors are believed to be in rubber rafts.

The proper Coast Guard authorities are notified at

2100Z on 22 June, and a search plane has been dispatched. It is due to arrive on the scene at 0100Z 23 June. The aircraft's navigation error (again a probable error) is estimated to be 10 miles.

2. Gathering Data

The first task of the search planner is to estimate wind, wind current, and sea current at the position of the sinking. Wind is obtained from observations, weather maps, Navy Fleet weather services, or the U.S. Weather Bureau, whichever is available. Wind current is computed from the wind by means of a graph given in the National Search and Rescue Manual. Average Sea Current is obtained from ocean current charts or pilot charts. These sources for average sea current are compiled from observations made over several years. (Thus this data may not be accurate for the time and place of concern, but so far they have been the only data available to the search planner.)

3. Drift Plotting

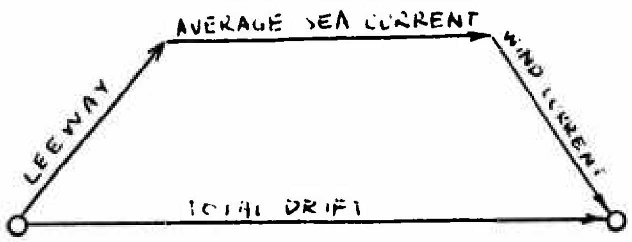
a. Leeway

Leeway is the motion of the survivor craft caused by wind. For the example case of a liferaft, two graphs are provided in the SAR Manual for computing leeway. One graph is for when a drogue is attached to the raft (a drogue is a type of sea anchor designed to retard liferaft leeway) and the other is for when a drogue is not attached. If it is not known whether a drogue is attached, both conditions are

considered separately.

b. Total Drift

Once leeway, wind current, and average sea scurrent have been determined, they are added vectorially to produce total liferaft drift.



This calculation can be done for intervals of any length - one hour, three hours, twelve hours - but the interval most commonly used is the interval between wind observations. That is if wind is available for 0900Z, 1200Z, 1500Z, etc., the search planner would probably compute total drift in three hour intervals, from 0900Z on the 22nd to 0100Z on the 23rd. Each time total drift is calculated (another probable error), 12.5% of that distance is retained as "drift error", and the drift errors are summed to obtain total drift error.

Example: In this manner, the position of the example liferaft is calculated to be 40-58.0N, 51-55.0W, and the drift error is 4.0 miles.

c. Minimax Plotting

If it is unknown whether a drogue was in use, two plots are made, and the final ("datum") position is defined to be midway between the two positions calculated.

The drift error is a function of the two calculated drift errors and the distance between the two positions. This process of plotting two positions is called Minimax plotting in the SAR Manual.

d. Error of Position

Once the datum has been computed, it is then necessary to find total probable error of position, c, where

de = total drift error

X = error in initial position of survivor craft

Y = navigation error of search craft

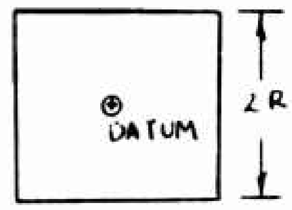
$$c = \sqrt{de^2 + X^2 + Y^2}$$

For the example, $c = \sqrt{16+100+900} = \sqrt{1016} = 31.9$ miles.

e. Safety Factor

To determine the size of the area to be searched, a search "radius", R is found by multiplying c by a safety factor, depending on which search in a sequence is being planned. For searches one through five, the respective safety factors are 1.1, 1.6, 2.0, 2.3, and 2.5. The example of the sunken fishing boat is a first search, so R = 1.1 x 14.7 = 16.2 miles.

The area to be searched, then, is a square with sides = 2xR, centered on datum:



f. Sweep Width

The standard measure of the effective search width of a search craft is called "sweep width". The value of the sweep width is obtained from a table in the Search and Rescue Manual, based on the type of target, search altitude, and meteorological visibility. The sweep width thus obtained is corrected for the effect of sea state by multiplying by a "whitecap correction factor" which is tabulated for various wind speeds.

C. THE COMPUTER PROGRAM

1. Objective

The computer program accomplishes the objective of providing an estimate of the survivor's position by automating the steps of the manual method of drift plotting.

2. Source of Weather Data

In choosing a source of weather data for the computer program, three criteria were considered: a. availability, b. computer access time, and c. accuracy. The final selection for data source was the Navy Fleet Numerical Weather Central, Monterey.

a. Availability

FNWC Weather data is compiled twice daily, at

0000Z and 1200Z, and is directly available, either by data link or, for testing purposes, on magnetic tape. For use with this program, the data is stacked chronologically on a master tape.

b. Computer Access Time

With the exception of the mounting of the master weather tape, all weather data handling is eliminated. Access speed, then, is limited only by the speed of the tape transport.

c. Accuracy

Although the data used is intended for wide area coverage, its probable error is less than the probable error assumed when computing drift error (12.5%). Although there will be occasions when local weather reports are available and may be more accurate, the bulk of search planning is done under conditions of incomplete weather analysis and forecasts, and when gross estimates must be made. Since the weather analyses for a particular time period and geographical location, once assembled for this program, are fixed parameters, repeated computations of the same search problem will always produce identical answers. This permits a rigorous evaluation of the data, methods, and assumptions used in search planning by a systematic testing procedure.

3. <u>Data Description</u>

The weather data are produced by FNWC for 3,969 geographical points in the northern hemisphere. These data

points are intersections of a 63 X 63 square grid superimposed on a polar stereographic map projection. Grid point (32,32) is at the north pole, and the vertical line (i=32) is coincidental with the 80 W and 100 E meridians. A sample projection is shown as Figure 1.

The polar stereographic projection provides a plotting reference which shows an entire hemisphere with the least possible distortion (Ref. 6), and the scale is true at 60 degrees North Latitude. Conversion from latitude (L) and longitude ($\underline{\lambda}$) to grid coordinates is accomplished by the following formulas:

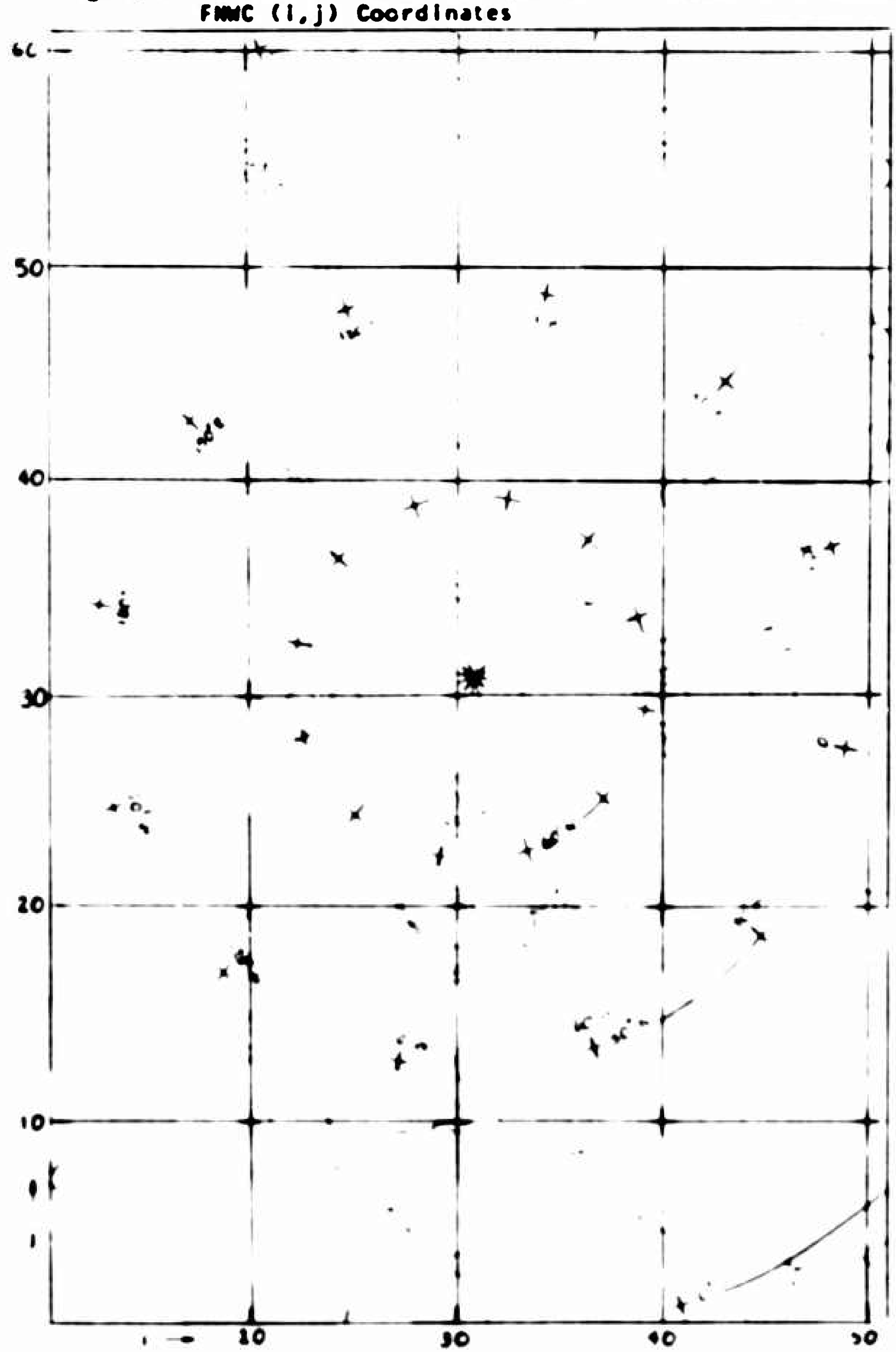
$$i = 32 + 31.205 \left(\frac{1 - \sin L}{1 + \sin L}\right)^{\frac{1}{2}} \cos(\lambda + 10^\circ) \tag{1}$$

$$j = 32 - 31.205 \left(\frac{1 - \sin L}{1 + \sin L}\right)^{\frac{1}{2}} \sin(\lambda + 10^\circ) \tag{2}$$

For the example, i = 38.008, and j = 19.0143.

The data is stored in "fields" of 3,969 words (numbers), each word being some component of atmospheric or oceanic conditions at its corresponding (i,j) grid position. The fields required for direct input to this program are:

Figure 1. Portion of Polar Stereographic Projection Showing FNWC (I,J) Coordinates



U Curr	U- component of surface current
V Curr	V- component of surface current
U Marine	U- component of surface wind
V Marine	V- component of surface wind

where the U direction is parallel to the "i" or horizontal axis and the V direction is parallel to the "j" or vertical axis, in the FNWC grid system.

The Current information as provided by FNWC is total surface current, including wind current.

Fleet Numerical did not regularly produce U Marine and V Marine wind fields, so these fields are computed by a separate computer program provided by the Weather Facility using the following data fields as input:

D 1000	Height of the 1000-mb pressure line
T Air	Air temperature at the surface
T Sea	Sea temperature at the surface

D. CALCULATING DRIFT WITH THE COMPUTER

1. Leeway

In addition to the liferaft drift tables given in the Search and Rescue manual, there are other ways to predict the leeway of a survivor craft. Most of these methods involve using a percent of the wind speed to

determine the leeway speed, and some deflection in degrees to determine the direction of leeway off the wind line. For example, a boat type may be known to drift in a direction 40 degrees off the wind line, and at a speed equal to 4% of the wind. To accomodate these methods as well as the liferaft drift table from the SAR Manual, several options are available to the user of this computer program.

2. Options for Leeway

a. A function approximating the liferaft drift tables in the National SAR Manual has been provided; drifting speeds for with drogue and without drogue are both available.

b. Leeway speed can also be specified as a percent of wind, in whole numbers, from 2% to 9%.

c. For each of the leeway velocities in b., a deflection off the wind line of plus or minus some angle, in tens of degrees, from 0 to 90 degrees, may be specified.

d. A minimum-maximum leeway speed option with the minimum being 1% of the wind, and the maximum being some whole number percent from 2% to 9% of wind speed, is available.

e. No leeway at all (as in the case of a man in the water or some other almost completely submerged object) may be specified.

3. Adjustment of Input Data

a. Dates

All dates are converted from month and day to julian dates, to permit reference to weather data and adjustment of the program "clock".

b. Latitude and Longitude

All initial positions are converted to FNWC (i,j) coordinates.

c. Leeway Options

Leeway options are entered by means of a two-digit code, which is converted to speed and direction of drift within the program.

d. Weather

Wind and current are provided in units of cm./sec. and are scaled in the program to nautical miles per hour. They are further scaled to decimal fractions of the FNWC grid distance.

6. <u>Interpolation of Weather Data</u>

a. Interpolation for Position

For each position in (i,j) coordinates there are four neighboring grid intersections for which weather is tabulated. Example:

GRID POSITION: i=38.00787

j=19.01613

GRID POINTS: . (38,20) . (39,20)

. (38,19) . (39,19)

All weather data are interpolated linearly among

these four neighboring points. For example, if U Current at 0000Z at grid points (i,j) is:

(38,20) = 50.0 (39,20) = 49.0

(38,19) = 42.0 (39,19) = 40.0

then for i=38, j=19.01413,

U Current = 42.0 + .01413 x (50-42) = 42.112

and for i=39, a similar computation results in U Current = 40.12717.

U Current for the position is then,

42.112 + .00787 x (-1.985) = 42.097 cm./sec.

b. Interpolation for Time

For each hour in the computation, there are two observation times which are used to supply weather data: 0000Z and 1200Z, one of which will be prior to the hour, and one which will be after the hour. A linear interpolation for position is done for each observation, and then these two values are interpolated linearly for time. For example, if the U Curr for 1200Z is calculated as above and found to be 37.25 cm./sec., the interpolation for time is accompli[illegible] as follows:

46.09 + 9/12 x (-8.84) = 39.46 cm./sec.

c. The Clock

A complete set of interpolations is done for each position and for each weather parameter at the start of the drift calculations, and each position is advanced for an hour's worth of drift. This interval is used as a

compromise between accuracy requirements and computer time. If an interval much smaller than one hour were used, a large increase in computer time would be required. A problem which would take 20 seconds at one hour intervals would cost almost 20 minutes of computer time if one minute intervals were used.

After the one hour's worth of drift is computed, and the positions updated, the clock is advanced one hour, and the process is repeated over and over until the end of the problem.

5. <u>Drift Plotting</u>

Drift calculations are applied to the (I,J) coordinates of the survivor craft plot. That is, the U-component of drift is added to the "I" coordinate of the survivor position and the V-component is added to the "J" coordinate.

Example: The interpolated values of current and wind for 0900Z on 22 June are

Parameter	cm./sec.	miles/hour
U Curr	+ 39.460	+ .766
V Curr	+ 36.128	+ .702
U Marine	+250.78	+ 4.87
V Marine	-850.25	-16.55

the wind speed then equals $\sqrt{4.87^2 + 16.55^2}$ =17.25 nautical miles/hour. For a liferaft without drogue, this wind speed produces a leeway of 0.94 miles per hour as

follows:

$$\text{Leeway} = .226 \times \sqrt{17.25} = 0.94$$

This formula is an approximation to the liferaft drift table given in the Search and Rescue Manual.

Since arctan (4.87/-16.55) equals 163.6 degrees, this angle is a measure of the wind angle (measured clockwise from the vertical (in the FNWC system):

If leeway deflection is specified by the user, it is applied to this wind angle, before the U and V components of leeway are calculated. The reduction of Leeway and wind angle to U and V components is as follows:

$$\text{U Leeway} = 0.94 \times \sin(163.6^{o}) = 0.266$$

$$\text{V Leeway} = 0.94 \times \cos(163.6^{o}) = -0.902$$

The leeway and current are applied to the position

as follows:

	U	V	
Leeway	.266	-.902	
Current	.766	.702	
Total	1.032	-.200	knots

These values are then divided by the distance between gridpoints, at this latitude = 235.37 miles:

	.00439	-.00085	
+ position	38.00787	19.01413	
New Position	38.01226	19.01328	for 1000Z 22 June.

This process is repeated hour by hour until the last datum has been calculated, drift plotting ceases, and calculations for position error and Search Radius begin.

6. Position Error

Just as in the manual method, the initial position error of the survivor craft is computed as follows:

x = distance of initial (or distress) position from last known position.

A = error of last known position

B = navigation error of survivor craft as a percent of distance traveled

The initial position error , X, is

$X = A + B x$

Since Y is the navigation error of the searcher, and de is the drift error, the Total Probable Error, c, of

Position is

$$c = \sqrt{X^2 + Y^2 + de^2}$$

7. <u>Safety Factor</u>

c, Total Probable Error of Position is multiplied by the safety factor to find the Search Radius as prescribed in the Search and Rescue Manual.

8. <u>Sweep Width</u>

A numerical approximation to the data in Richardson's Sweep Width tables (Ref. 4) may be seen to be:

$W = -3.34377 + 1.25887 \log(l) + 2.55442 \log(V) + .01023\ h$

where l is boat length

V is visibility in miles, and

h is search altitude in thousands of feet.

In addition, corrections to Sweep Width for whitecaps based on wind speed (v) and cloud cover (C) can be approximated by:

$F1 = .886 + .298X - .116\ X^2$ (whitecaps, $X = v/10$)

$F2 = 1.131 - .472C + .152C^2$ (cloud cover)

These correction factors are multiplied by W to obtain final Sweep Width. This Sweep Width function is applicable to small boats only. No Sweep Width for large ships or for liferafts is available in the program.

E. VERSIONS OF THE PROGRAM

The Search Planning Program is written in FORTRAN IV for

use on a remote computer terminal. A second version is written for use on the operations computer at Fleet Numerical Weather Facility. No remote terminal operation is available there, so these two versions are different in several ways:

1. Input-Output

a. The time sharing version is written for entry of data by the search planner onto a remote console, and the results are printed out immediately on the same console. This permits the planner to control the program during execution, and to make intermediate decisions concerning the problem. An example of the output of the time-sharing version is shown on the next two pages. Note that items typed in by the user are shown in lower case, and the replies typed on the console by the computer are in upper case. The final output includes sweep width, total probable error of position, search radius, and calculated wind.

b. The batch-processing version at FNWC differs from this in that it requires cards to be punched for input, and the output is printed in message form, ready for transmission back to the requestor.

2. Features Omitted

For the operational version of the program at Fleet Numerical Weather Facility the following items of output shown on the sample time-sharing printout were not made available:

```
  $ sar
  EXECUTION BEGINS...
    MONTEREY SEARCH PLANNING PROGRAM
  ENTER LEEWAY CODE, 1 BLANK, THEN DESCRIPTION
> 11 liferaft
  HOW MANY STARTING POINTS WILL BE ENTERED?
> 1
  LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:
  070930Z MAR,3822.5N,06806.5W
> 220900z jun,6042.0n,05213. 0w
     60        42.0     52        13.0    CHECK:N    W
   CHECK. TYPE Y OR N
> y
  ENTER NUMBER OF TIMES DATUM IS TO BE COMPUTED NOW:
> 2
  ENTER THESE DTGS.  EX:020900 MAR,031030 MAR
> 230100 jun,230700 jun
  SEARCH 1, TRACK  1, DATUM:     60 50.21     51 51.96
  SEARCH 2, TRACK  1, DATUM:     60 53.26     51 44.04
  ENTER LAST KNOWN POSITION. EX: 3522.0N,07653.0W
> 6100.0n,05600.0w
  IS LIFERAFT
  A (1)BOAT, (2)SHIP, OR (3)AIRCRAFT?(ENTER 1,2,OR3)
> 1
  ENTER SEARCH UNIT FIX ERROR, Y. EX: 5.0
> 5.0
  INDICATED DISTRESS CRAFT POSITION ERROR,X:
  X= 15.00(1) +  0.15(2) TIMES DIST. FROM LAST KNOWN POSITION.
  ANY CORRECTIONS? (TYPE 0,1,2, OR 12)
> 1
  ENTER PARAMETER(1):
> 20.0
  IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?
> no
  ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:
  •• 1 0 SEARCH:
> 1
  •• 2 0 SEARCH:
```

```
> 0
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
  1:  0 SEARCH:
 60-50.2N      51-52.0W     POS. ERROR:  61.8, RADIUS:  66.0 MILES;
                WIND 36.6KTS   FROM 267.
 SWEEP WIDTH?  Y OR N
> Y
 ENTER SEARCH ALTITUDE (EX:800.)
> 1000.
 ENTER VISIBILITY IN MILES (EX:10.0)
> 20.0
 ENTER BOAT LENGTH IN FEET  (EX:36.0)
> 10.
 ENTER CLOUD COVER IN FRACTION (EX: 0.9)
> 0.1
 SWEEP WIDTH=        6.6 MILES.
 THE FOLLOWING ARE THE DATUM POINTS FOR THE
  2:  0 SEARCH:
 60-53.3N      51-66.0W     POS. ERROR:  61.9, RADIUS:   0.0 MILES;
                WIND 36.6KTS   FROM 267.
 GOOD LUCK ON YOUR SEARCH! LET ME KNOW IF YOU FIND
 THELIFERAFT


 IHC0021 STOP      0
 R; T=1.00/2.87 15.11.18
```

Note: Inputs marked with ">"

a. Printout of intermediate track positions (SEARCH 1, TRACK 1, etc.) is not produced.

b. On scene Wind

Since the wind printout as shown in the sample time-sharing output is only the wind velocity and direction at the beginning of the search, and may not be representative of the average weather conditions throughout the search, this value is not included.

c. Sweep Width

Since the the computation of sweep width requires data which may not be immediately available to the search planner at the time of his request, and since the formula applies only to small boats, this feature was not included in the Fleet Numerical version.

d. Leeway

For the Fleet Numerical version, leeway is calculated as described in D.2. The time sharing version uses a square root function for all leeway. If N is the percentage drift specified (1% to 9%), the leeway function in the time sharing version is

$$\text{LEEWAY} = \frac{N}{25}\sqrt{\text{WIND}} \qquad (3)$$

This function produces leeway which is equal to N% of the wind for wind speeds of 16.0 knots. For other wind velocities the function follows the general contour of the liferaft leeway (without drogue) table in the Search and Rescue Manual.

III. SEARCH THEORY

In part III the method of estimating the position of the search object and the rules for determining the size of the search area were discussed. This is only part of the search planning process; this section will consider how resources are assigned to the search, and how the effectiveness of the search is measured.

In a search pattern employing parallel sweeps, the distance between these sweeps is called track spacing, S. The Search and Rescue Manual recommends that for urgent cases the track spacing used be equal to the Sweep Width, W, and for less urgent cases it be equal to twice the Sweep Width. Once the value of track spacing has been decided upon, the amount of searching required (in miles flown) L can be computed from S and the area A to be searched:

$$L = A/S$$

The measure of effectiveness of a search which is given in the Search and Rescue Manual is called Probability of Detection, and it is presented as a series of curves plotted against "coverage factor" or W/S. These curves are called

"first search", "second search", etc., probabilities. If p is the probability of detection in the first search curve, the probabilities 2,..n..5 are given by

$$p = 1 - (1 - p)^m$$

These curves do not take into account the size of the area searched, however, so that a search can be conducted in a very small area using a high coverage factor which will yield a very high probability of detection according to the graph. Common sense indicates that to confine the search to a very small area will probably not result in the detection of the target. Nowhere does the Search and Rescue Manual define the probability that the target is in the search area.

The absence of the treatment of this seemingly critical factor led the author to a review of the field of search theory as it applies to survivor search.

The basis for most of the search planning criteria in the National Search and Rescue Manual was found in Koopman's (1946) work, <u>Search and Screening</u> (Ref. 2). This treatise developed the concept of sweep width, and found the probability of detection for various situations.

A. DETECTION LAWS

1. <u>Instantaneous Probability of Detection</u>

If γ is defined so that the probability of detecting a target in a short period of time dt is γdt, then the quantity γ is called the instantaneous probability density of detection. When the searching is done during a time t under constant conditions, the probability p(t) of detection is given by

$$p(t) = 1 - e^{-\gamma t} \tag{4}$$

<u>Search and Screening</u> developed this quantity for various situations.

a. Definite Range Law

This law assumes that there is a certain range R from the observer beyond which it is impossible to detect the target; inside this range detection is certain. Instantaneous probability of detection by this law is

$$\begin{aligned} \gamma(r) &= \infty \qquad r \leq R \\ \gamma(r) &= 0 \qquad r > R \end{aligned} \tag{5}$$

b. Inverse Cube Law

The inverse cube law is the result of making the following assumptions:

(1) The observer is at an altitude h above the ocean.

(2) The observer detects the target by seeing its wake.

(3) The instantaneous probability of detection

is proportional to the solid angle subtended at the point of observation by the wake.

The calculation of the solid angle is shown in figure 2.

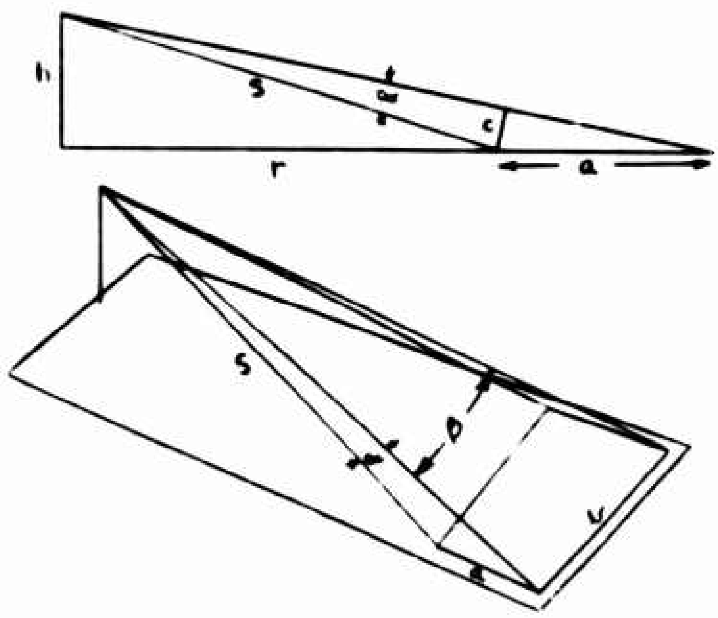


Figure 2. Calculation of Solid Angle

Solid Angle $= \alpha\beta$

$\alpha = c/s \;, \quad \beta = b/s$

but $c/a = h/s$

thus $c = a\,h/s$

Solid Angle $= a\,b\,h/s^3 = a\,b\,h/(r^2+h^2)^{3/2}$

Since γ was assumed to be proportional to the solid angle,

$$\gamma = \frac{k\,h}{(h^2+r^2)^{3/2}}$$

where k included all factors such as meteorological visibility, etc.

Assuming further that in the majority of cases r is much larger than h, then

$$\gamma = \frac{kh}{r^3}$$

2. <u>Lateral Range</u>

When the observer and the target are on their straight courses at constant speeds for a long time before and after their closest point of approach the probability of detection may be shown to be a function only of the distance at closest point of approach. This distance is called the <u>lateral range</u>, and is denoted as x. This probability of detection, p(x), plotted against lateral range, is called the <u>lateral range curve</u>.

Twice the area under the lateral range curve is defined as effective search width (or Sweep Width),

$$W = 2\int_0^{+\infty} p(x)\,dx \qquad (6)$$

Koopman shows that:

> "The effective search width is twice the range of a definite range law of detection which is equivalent to the given law of detection in the sense that each of the two laws detects the same number of uniformly distributed targets of identical velocity."

Thus, for the definite range law of detection p(x) = 1 if $x \leq R$, and p(x) = 0 if x > R, so that W = 2R. To find W for the inverse cube law, first p(x) may be shown to be

$$p(x) = 1 - e^{-\frac{2kh}{w^2}} \tag{7}$$

where w is searcher's speed.

From (6),

$$W = \int_{-\infty}^{+\infty} 1 - e^{-\frac{2kh}{wx^2}} \tag{8}$$

$$= 2\sqrt{\frac{2\pi kh}{w}} \tag{9}$$

3. Random Search

To find the probability of detecting a target known to be in an area A, where both searcher and target are moving over the ocean in complicated paths, the situation called random search may be considered. This requires the following assumptions:

a. The target's position is uniformly distributed in A, given it has not been detected

b. The observer's path is random in A in the sense that it can be thought of as having its different (not too near) portions placed independently of one another in A.

c. W is small with respect to the area A.

If the searcher's path, of length L, can be considered to be composed of n separate and equal portions of length L/n, then the probability that the target be detected in any one path is WL/nA. The probability that the

target not be detected at all, then is

$$p = 1 - \left(1 - \frac{WL}{nA}\right)^n \tag{10}$$

and for large n,

$$p = 1 - e^{-WL/A} \tag{11}$$

This is the formula of random search.

4. <u>Parallel Sweeps</u>

The most common method of non-random searching is one which uses a series of straight parallel sweeps a distance S (or track spacing) apart, where the position of the target is fixed with relation to the sweeps. Let the target be uniformly distributed in an area of size A. Search and Screening gives the following result for P(L), the probability of detecting with path length L=A/S.

(1) Definite Range Law

Since detection will surely occur if the target is within the detection range W/2, then the probability of detection is equal to the coverage factor W/S.

Thus,

$$\begin{aligned} p &= WL/A \qquad L \leq A/W \\ p &= 1 \qquad\quad\; L > A/W \end{aligned} \tag{12}$$

(2) Inverse Cube Law

$$p = \operatorname{erf}\left(\frac{\pi\sqrt{2m}}{S}\right) = \operatorname{erf}\left(\frac{\sqrt{\pi}}{2}\,\frac{WL}{A}\right) \tag{13}$$

(3) Uniform Random Search

From (11),

$$p = 1 - e^{-WL/A}$$

or when S=L/A,

$$p = 1 - e^{-W/S} \qquad (14)$$

The three probabilities using parallel sweeps are shown in Figure 3.

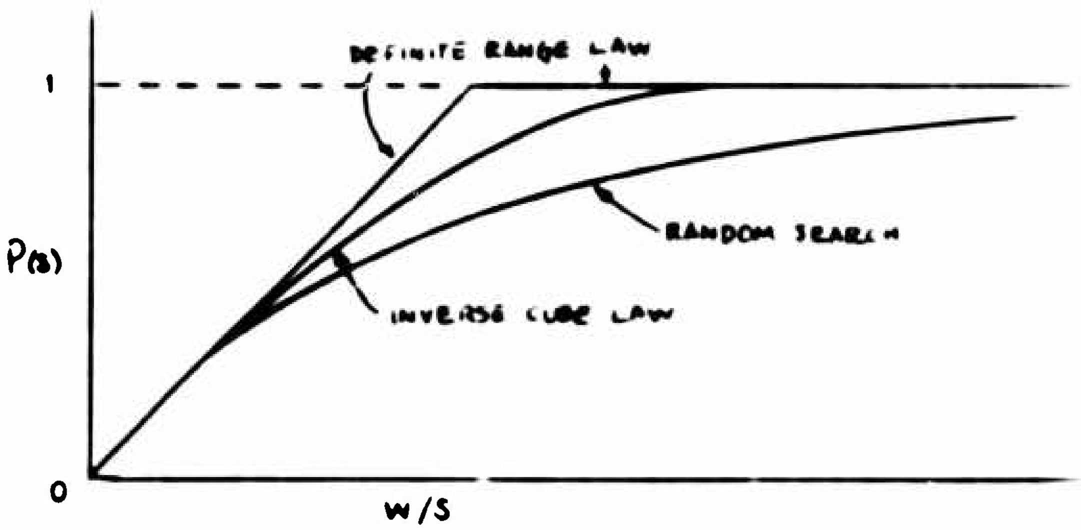


Figure 3. Probability of Detection

B. DISTRIBUTION OF SEARCH EFFORT

1. General

Another result in Search and Screening involves the definition of search effort density as a function of (x,y) in A.

If B is the area of a subregion in A, and L is the

length of the observer's path in B, then the expression L /B is defined to be the observer's <u>track</u> density in B. As B becomes very small (approaches a point (x,y)) the <u>search</u> density $\varphi(x,y)$ is the limit of WL /B, or Wl(x,y), where

$$\iint_A l(x,y)\,dx\,dy = L \tag{15}$$

and

$$\iint_A \varphi(x,y)\,dx\,dy = WL = E \tag{16}$$

Thus if (x,y) is applied at (x,y), the probability of detecting a target located there is

$$p = 1 - e^{-\varphi(x,y)} \tag{17}$$

Given the search density function $\varphi(x,y)$ and the target's distribution p(x,y), the probability of detecting the target is

$$P(\varphi) = \iint_A p(x,y)\left(1 - e^{-\varphi(x,y)}\right)dx\,dy \tag{18}$$

The $\varphi(x,y)$ which maximizes $P(\varphi)$ is shown by Koopman to be

$$\varphi(x,y) = \log \frac{p(x,y)}{b} \tag{19}$$

when (x,y) is in A, and

$$\varphi(x,y) = 0 \tag{20}$$

when (x,y) is not in A ,

where A denotes that portion of A in which the expression (19) is non-negative. The value of b is determined by using equation (16).

2. <u>Normal Target Distribution</u>

If the target's distribution is a bivariate circular normal distribution about a point(0,0) in a cartesian coordinate system,

$$p(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{r^2}{2\sigma^2}} , \quad r^2 = x^2 + y^2 \tag{21}$$

then the search effort density which maximizes P(φ) is

$$\varphi(x,y) = \frac{a^2 - r^2}{2\sigma^2} \qquad r \leq a \tag{22}$$

and

$$\varphi(x,y) = 0 \qquad r > a \tag{23}$$

Thus letting a be the radius r at which p(x,y) assumes the critical value b,

$$A_b = \pi a^2 , \quad b = \frac{1}{2\pi\sigma^2} e^{-\frac{a^2}{2\sigma^2}} \tag{24}$$

where

$$a = \left[\frac{4\sigma^2 E}{\pi}\right]^{\frac{1}{4}} \tag{25}$$

The form of this equation is an inverted parabola of revolution with its center at (0,0) with a maximum value of $a^2/2\sigma^2$.

IV. THE UNIFORM COVERAGE SQUARE SEARCH

Although (19) gives the "optimum" search effort distribution, this optimum distribution is difficult to achieve in practice. Flying in a large circular area with a continuously varying effort is no simple navigational task. Much easier is the common practice of (1) defining a square area with its center at the center of the target's distribution and (2) conducting a regular search of uniform density throughout this area. If the target is not found, then (3) the area is expanded and the search repeated. Although a single search of this type does not conform to the parabolic optimum search effort distribution, a series of them, each larger than the one before, may be a very good approximation.

The most important advantage of this plan is its ease of navigation, allowing the pilot(s) free time to look for the target.

A. THE PROBLEM

The problem was to determine the optimum size of a square area within which a uniform search with parallel sweeps is to be conducted.

B. TERMS

The terms and definitions in the Search and Rescue Manual differ from those in Search and Screening. In the Search and Rescue Manual, probability of detection is used only for the probability of detection with parallel sweeps, (given a uniform target distribution within the search area). In order to avoid confusion, the following terms are defined:

P - Probability of Success - The probability that on a given search the target will be found.

p - Location Probability - The probability that a target is within a specified area.

d - Probability of Detection - The probability of detecting a uniformly distributed target given parallel sweeps.

W - Sweep Width - The effective search width of the searcher; the area under the lateral range curve.

S - Track Spacing - The mean distance between adjacent parallel sweeps of the searcher.

L - Path Length - The total number of miles flown by the searcher within the search area.

c - Probable Error of Position - Probable error of the target's position from datum; given a normal distribution, c=1.18 x standard deviation of the target's distribution.

R - Search Radius - The search radius is defined as one-half the side of a square

search area.

C. THE SOLUTION

1. The Objective

The objective is to maximize the Probability of Success P, where the detection function for a uniformly distributed target known to be in the area is defined as d(W,L,R,x,y). P is expressed as

$$P(W,L,c,R) = \int_{-\infty}^{\infty}\int p(x,y)\, d(W,L,R,x,y)\, dx\, dy$$

For a uniform search, the probability of detection is constant and equal to d(W,L,R) inside the search area A, and is zero outside, (given uniform visibility and other factors), and so d(W,L,R) can come out of the integral:

$$P(W,L,c,R) = d(W,L,R) \iint_A p(x,y)\, dx\, dy$$

It is convenient to choose x and y as distances in a cartesian coordinate system with the target's most likely position (datum) at (0,0).

2. Calculation of Individual Terms

Based on the inverse cube law for parallel sweeps,

Koopman derives the following expression for probability of detection, from (13):

$$d(s) = erf\left(\frac{\sqrt{\pi}}{2}\ \frac{W}{S}\right)$$

where $S = A/L = (2R)^2/L$.

This is equivalent to the "First Search" probability of detection given in the National Search and Rescue Manual.

The location probability, p, is given by the formula for the circular bivariate normal distribution:

$$p(R) = \iint_{x,y=-R}^{x,y=+R} \frac{1}{2\pi\sigma}\ e^{-\frac{x^2+y^2}{2\sigma^2}}\ dx\,dy$$

Where R defines a square centered at (0,0) with sides =2R.

Figure 4 is a graph of this function, along with a similar curve showing the cumulative probability for a circle with radius R. Since the square area is actually larger (it is circumscribed about the circle) its probability for any radius R is greater. However, if these cumulative probabilities are plotted against the area of the search, the probability for a square will be slightly less than for a circle (see figure 5). Although there is some loss of efficiency in searching a square instead of a circle, this loss is very minimal, about 1%.

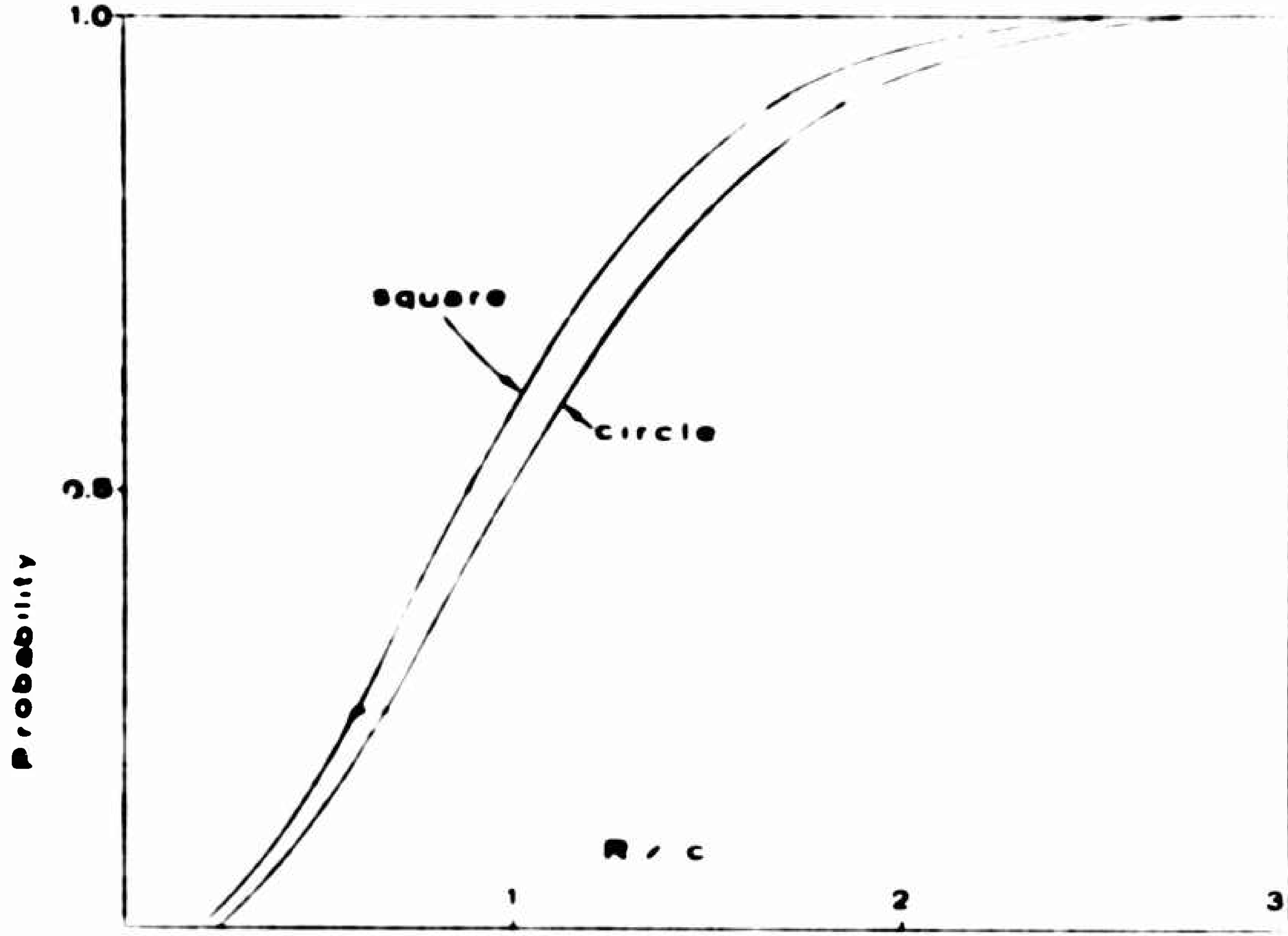


Figure 6. Cumulative Probability for Circle with Radius R and for Square with Sides equal to 2R.

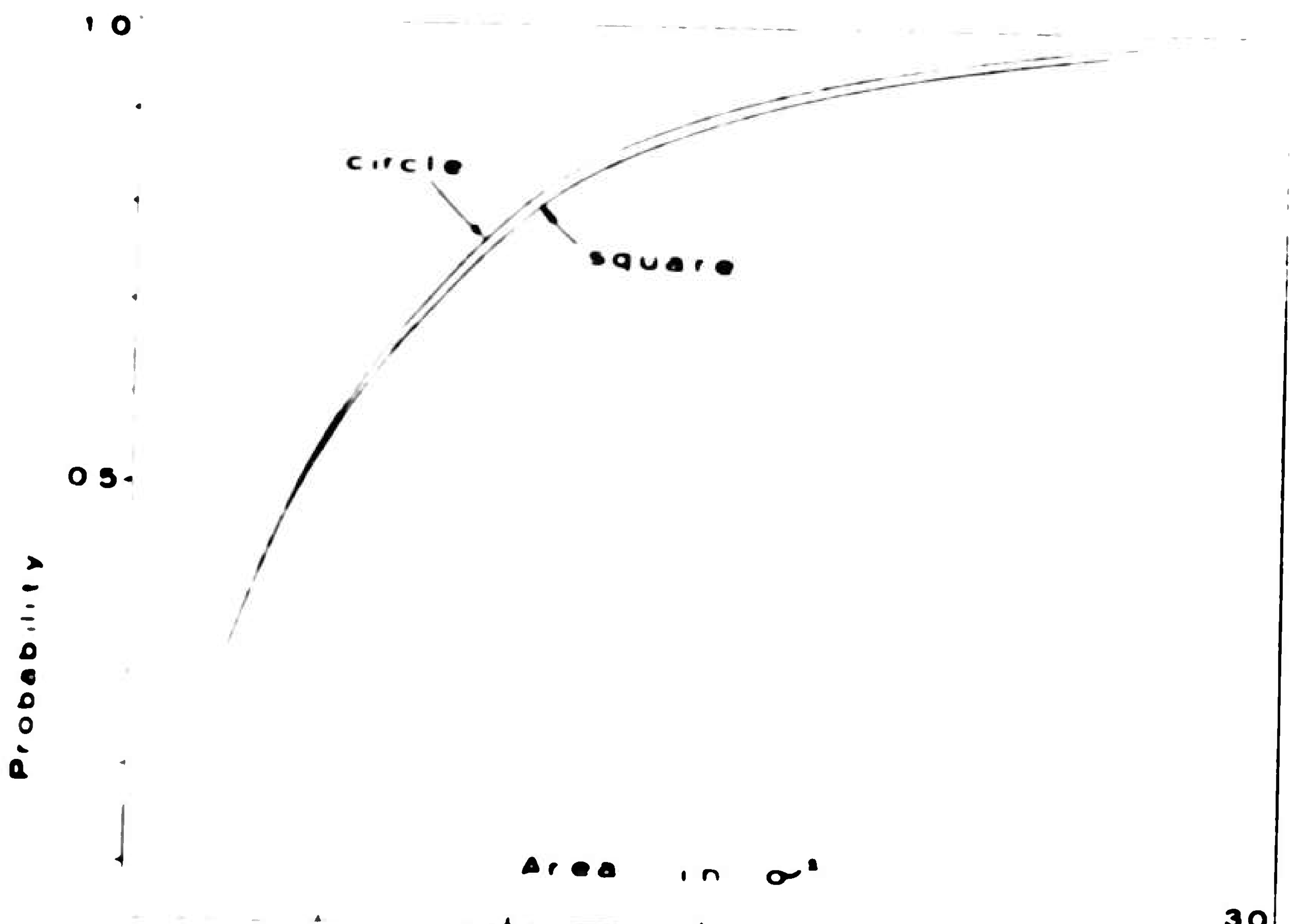


Figure 5. Cumulative Probability for Circle and Square Plotted against Area.

NOTE: Although the standard deviation is the commonly accepted measure of variability, the National Search and Rescue Manual uses the term, "Total Probable Error of Position". Its value is computed using estimates for drift error, target's position error, and search craft navigation error. These errors are squared and added, and then a square root is taken to produce Total Probable Error. This term is not specifically defined in that publication, so that one of the objectives of this solution was to demonstrate that it is equivalent to the statistically well-defined term 'Probable Error', which is a median error: that is, half of all errors have absolute values greater than that error, and half have absolute values which are smaller. The absence of this definition is a gap in the present search planning process, because planners are called upon to make estimates of errors without knowing how these errors are defined.

3. The General Solution

To determine the optimum size for a square search, given a certain amount of searching miles available (L), sweep width (W), and probability distribution (p(x,y)), a straightforward maximization method is employed in the following sequence:

a. Determine total effort, E.

$E = W \times L$

b. Choose some arbitrary initial search radius, x.

c. Determine the search area, A, for this x:

$A = 4x^2$

d. Determine effort density for a uniform search:

$\frac{WL}{A} \left(= \frac{W}{S}\right)$

e. Determine probability of detection d from (3).

f. Determine the probability p from (2), with R = x.

g. Determine the probability of success,

$$P(x) = p(x)d(x).$$

h. Increase x by Δx and repeat calculations. If P(x) increases, continue adding Δx until a local maximum is encountered. If P(x) decreases initially, reduce x by $2\Delta x$ and continue <u>subtracting</u> Δx until a local maximum is reached.

Since a cumulative probability distribution is continuous and has a slope throughout its range of ≥ 0, and since the probability of detection function d(x) is continuous with a slope of < 0, the function $P(x) = p(x)d(x)$ can be shown to be unimodal, and so a local maximum in P(x) will be an absolute maximum.

4. <u>Application</u>

The first use of this method was to check the National Search and Rescue Manual's recommended search planning guidelines to see if they produce square searches of optimum sizes. These guidelines are given in the form of

'Safety Factors', or search radii, for repeated searches, as multiples of Total Probable Error of Position, e.g.,

Search	Safety Factor
1	1.1
2	1.6
3	2.0
4	2.3
5	2.5

As far as effort density is concerned, there are two recommendations given in the SAR Manual. One is for a track spacing equal to sweep width, for urgent cases, and the other for a track spacing equal to twice the sweep width, for less urgent searches. Both of these recommendations were tested.

The approach used was:

a. Set some arbitrary value for W

b. Set S=W so that WL/A. =1.

c. Find R from "safety factor" table for the appropriate search (starting at 1).

d. Find path length, L:

$$L = \frac{4R^2}{S}$$

e. Beginning at x = R, and with W and L above, use the general solution process described in paragraph 3. to

find x', the optimum search radius for that path length.

f. Assuming that the <u>optimal</u> search is executed unsuccessfully, reevaluate the target's distribution p(x) (see Para. 5.) and repeat the process from c. above. After five successive searches have been computed, stop the computation.

g. Compare the resulting five optimum sizes with the sizes recommended in the Safety Factor table from the Search and Rescue Manual.

5. <u>Bayesian Analysis</u>

Bayes' Law of Probability says that an estimate of the probability of a hypothesis can and should be revised on the basis of the outcome of a related event. In the case of search theory, the hypothesis is that the target is inside a given area. A search is conducted, and the event is either the detection or the non-detection of the target. This event should revise the initial estimate of the probability that the target was in the area. Of course, if the event is detection, the new probability that the target is in the area is 1. If the event is non-detection, then Bayes' formula must be used to calculate the new probability.

1. <u>Example</u>

The probability that a target is in a certain search area has been determined to be 50%, and a search is conducted in this area with a uniform probability of detection of 50%. The resulting probability cf success is .5

x .5 = .25 or 25%.

For the use of Bayes' formula, the following terms are defined:

- A The hypothesis that the target is in the area.
- $\bar{A}$ The hypothesis that the target is not in the area.
- D The event of detection.
- $\bar{D}$ The event of non-detection.

Then

$$p(A|D) = \frac{p(A) \cdot p(D|A)}{p(A) \cdot p(D|A) + p(\bar{A}) \cdot p(D|\bar{A})}$$

When the target is detected:

$$p(A|D) = \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 0.0} = 1.0$$

as expected. If the target is not detected, the new probability would be

$$p(A|\bar{D}) = \frac{p(A) \cdot p(\bar{D}|A)}{p(A) \cdot p(\bar{D}|A) + p(\bar{A}) \cdot p(\bar{D}|\bar{A})}$$

$$= \frac{0.5 \times 0.5}{0.5 \times 0.5 + 0.5 \times 1.0} = \frac{1}{3}$$

Whereas the target had a 50% *a priori* probability of being in the search area, its new, or *a posteriori* probability of being in the area is 33.3%.

For the solution in paragraph 4., the entire probability distribution of the search object was reevaluated between successive searches. This was done for p(x) inside the search area by

$$p'(x) = \frac{p(x)(1-d)}{(1 - p(R)d)} \tag{26}$$

and for p(x) outside the search area by

$$p'(x) = \frac{(p(x) - p(R))}{(1 - p(R)d)} + p'(R) \tag{27}$$

where R is the radius of the search conducted.

In order to illustrate the general form of the probability distributions between searches, a function was used which is similar to a density function. This function, f(x) was defined to be

$$f(x) = \left(\frac{d(p(x))}{dx}\right)\left(\frac{1}{8x}\right) \tag{28}$$

where x is the measure of radius, or again, one-half of one side of a square, and 8xdx is the differential of

area (Figure 6).

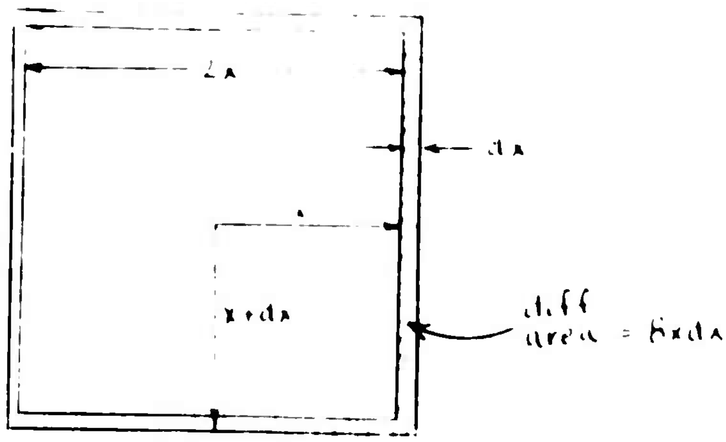


Figure 6. Derivation of Density Function for Square Area

Curve 1 in Figure 7 is the density function before any searching is done, as derived by (28) from (21). Curves 2 through 5 are these functions after successive searches.

Figure 8 is a similar set of curves showing the cumulative probability distributions.

6. <u>Results</u>

This method (from 4.) gives the following optimum searches:

Search	Optimum Radius	Safety Factor
1	1.08	1.1
2	1.64	1.6
3	2.07	2.0

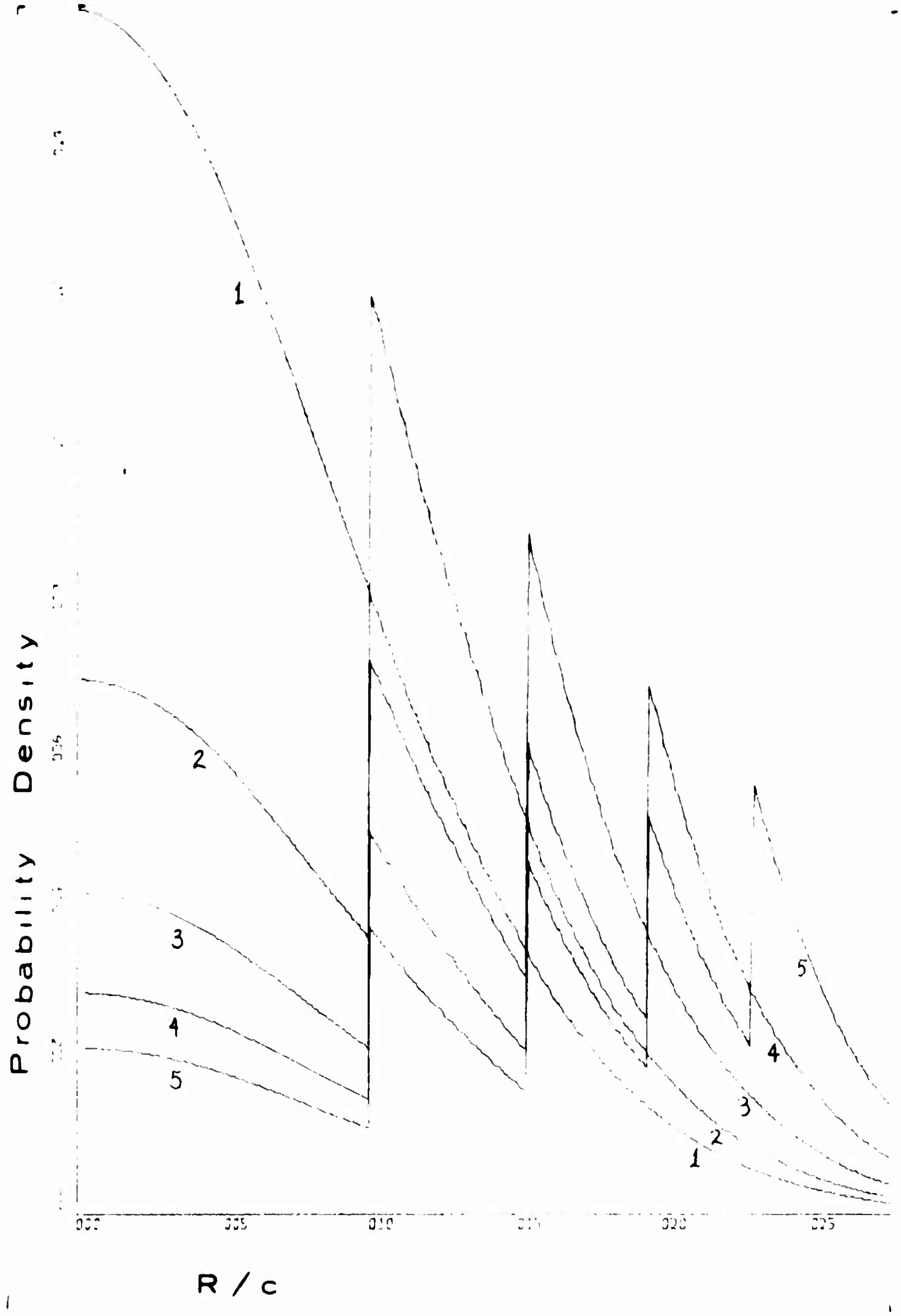


Figure 7. Probability Density with Application of Bayes' Law Between Successive Optimum Square Searches.

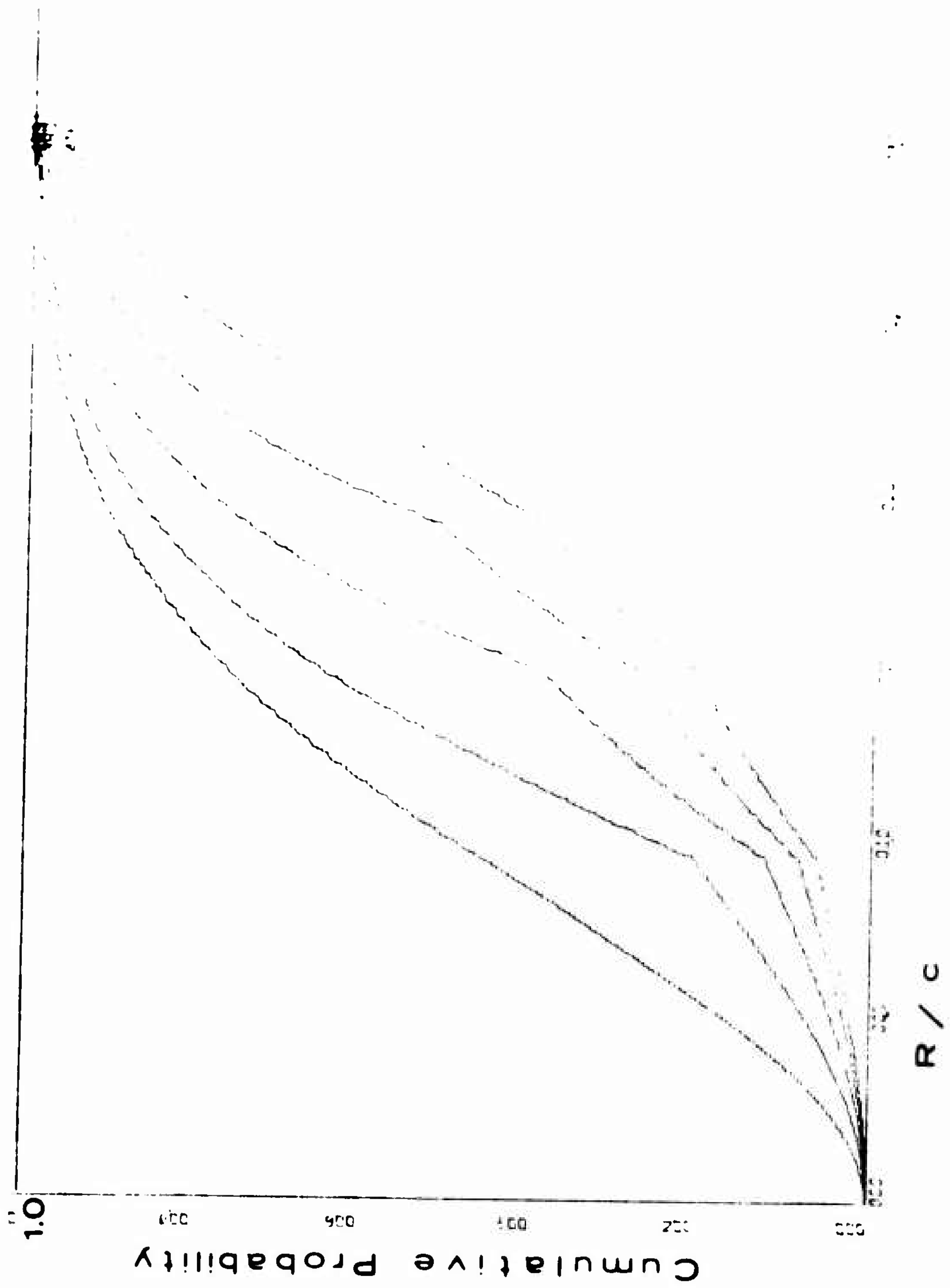


Figure 8. Cumulative Probability with Application of Bayes' Law Between Successive Optimum Square Searches.

4	2.43	2.3
5	2.74	2.5

Since these results were very close to the 'Safety Factors' listed above, it was concluded that (1) the safety factors were originally good calculations, and (2) they were calculated using the mathematical definition of probable error.

It should be noted, however, that these safety factors are close to optimum search radii only for the condition where track spacing equals sweep width. The second recommendation, track spacing equals twice sweep width, does not produce anywhere near optimum search areas. When a track spacing S' equal to twice the sweep width is used, the new path length L' is given by

$$L' = \frac{4R^2}{S'} = \frac{4R^2}{2W} = \frac{1}{2}L$$

For this new path length, optimum search sizes were found to be:

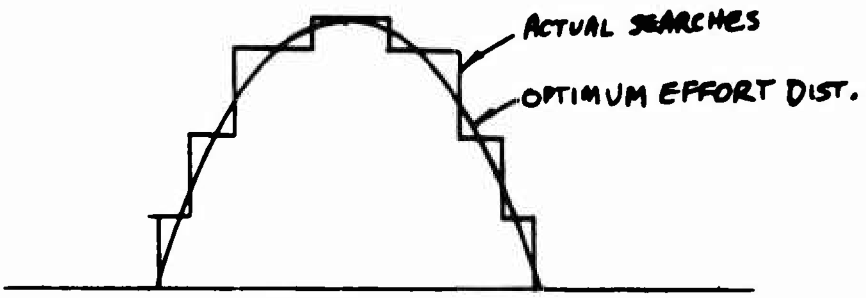
Search	Optimum Radius
1	0.85
2	1.30
3	1.66
4	1.95
5	2.20

When there is less search effort available the size of the search area as well as the effort density should be reduced. The SAR Manual gives no guidance as to how much the area should be reduced with a given amount of available effort. Conversely, there is no indication as to how excess search resources should be used, if such a condition should exist.

What is needed is some way for the search planner to determine the optimum search configuration directly from the amount of search effort available.

D. THE GENERAL CASE

Assume that a series of optimum square searches, each larger than the preceding one, is a good approximation of an optimum search effort distribution. Consider all the searches of the series combined into one search effort, so that the search effort density $\phi(r)$ assumes a step function which is close to the ideal effort density.



The radius r of the combined search is equal to the

radius of the last (and the largest) individual search in the sequence.

If the search had been a circular one, and if the effort density had conformed to the optimum, the expression for this radius would be

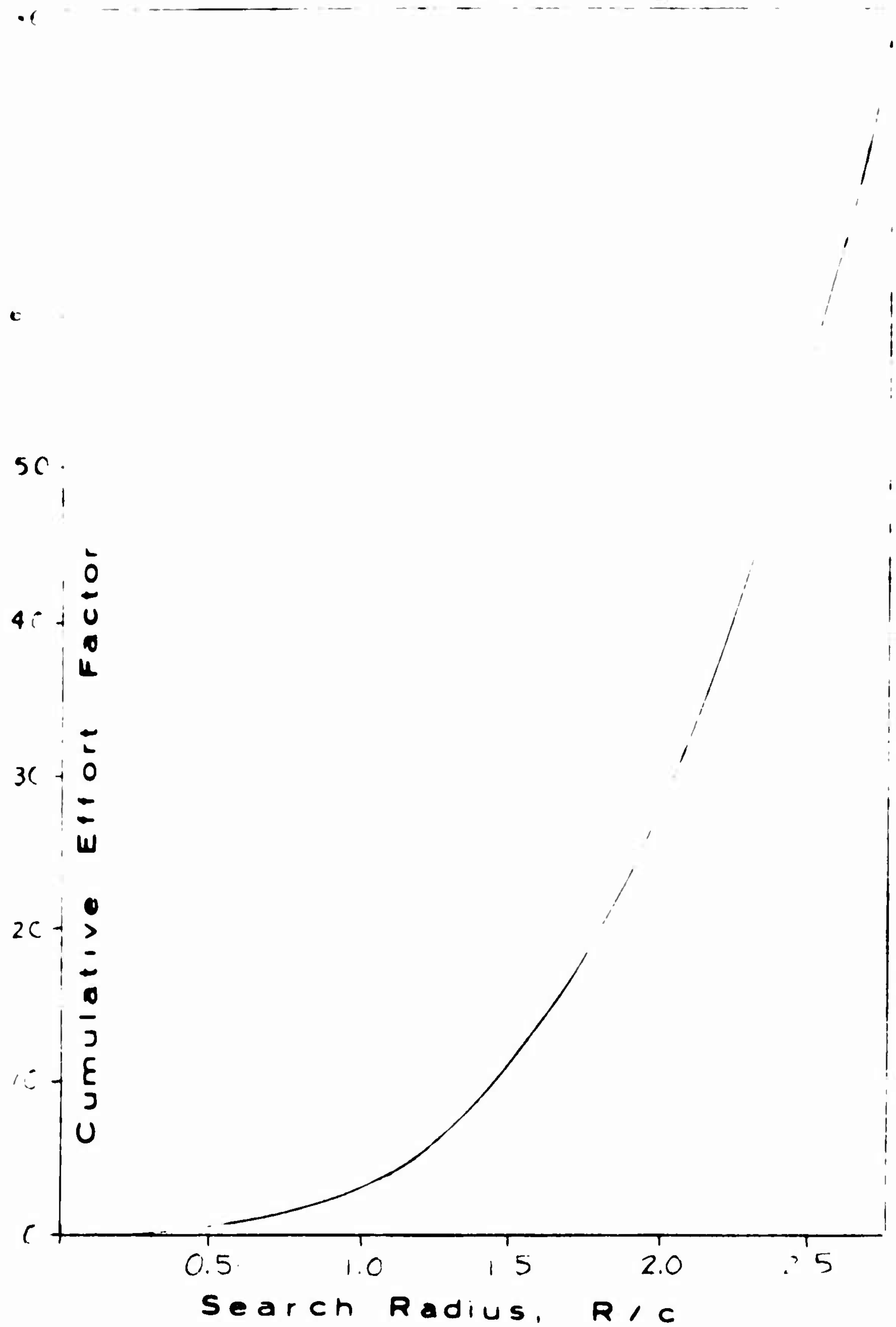
$$a = \left[\frac{4\sigma^2 E}{\pi}\right]^{\frac{1}{4}}$$

But since the search is composed of a small number of square searches, this same formula is not expected to apply. There should, however, be some way to approximate a function which will define the optimum radius based on available effort and the target's distribution. The simplest way to do this is to compute total search effort for a few optimum square searches, plot the radius of each of the searches against the cumulative search effort, and attempt to smooth a curve through them.

This was done for the ten searches (five at W = S and five at W = 2S) calculated above, and the resulting curve is shown in Figure 9. Just as radius is in terms of probable error, so are the factors W and L of total effort 'normalized' by dividing each by probable error. Thus 'normalized' effort is a multiple of the <u>square</u> of probable error.

It should be cautioned that the curve is only an

Figure 9. Optimum Size of Square Search based on Cumulative Normalized Effort Factor.



approximation, and will not be valid if the effort available for a single search is very large. Thus if a search is computed which shows a coverage factor (W/S) greater than 1.8, then the results of the curve will not give an optimum search, and some other method will be required. Again, the effort plotted is cumulative, so that all the effort exerted in earlier searches must be added to the effort available for the present search before entering the table.

<u>Example</u>: One 150-knot aircraft is available for six hours of searching; the total probable error of position has been calculated to be 31.9 miles, and W is estimated at 10 miles.

Total effort then is found as follows:

E= 150kts X 6hrs X 10miles(W)

= 9000 square miles

In terms of probable error, (c=31.9)

E(normalized) = 9000/(31.9 X 31.9) = 8.9

From the graph, r = 1.4,

R = 1.4 X c = 44.6 miles, or 89.2 miles on a side, and

S = 4 X R X R / L = 8.75 miles.

If the target is not found on the first search, and a second is to be conducted, the amount of available effort is calculated for the second search. The normalized effort for this search must be combined with all previously expended effort before entering the graph. Thus if t(normalized) for the second search is calculated to be 10.0, the graph should be entered with a figure of 10.0+8.9 or 18.9 to find the radius of the second search. Each search area will be larger than the preceding one.

This decision curve should prove to be a more flexible tool for search planning than the Safety Factor table, since it provides a continuous range of search radii for different amounts of effort available.

V. THE SECTOR SEARCH

There is one search pattern in general use which does effect a greater concentration of effort at the center of the search area, and that is the sector search. This search pattern is executed by a series of sweeps crossing over the center of the search area at various angles. These sweeps are connected at their endpoints by chords flown near the perimeter of the area. This pattern covers a circular area and, perfectly navigated, produces a track as shown in Figure 10.

A. SEARCH EFFORT DISTRIBUTION

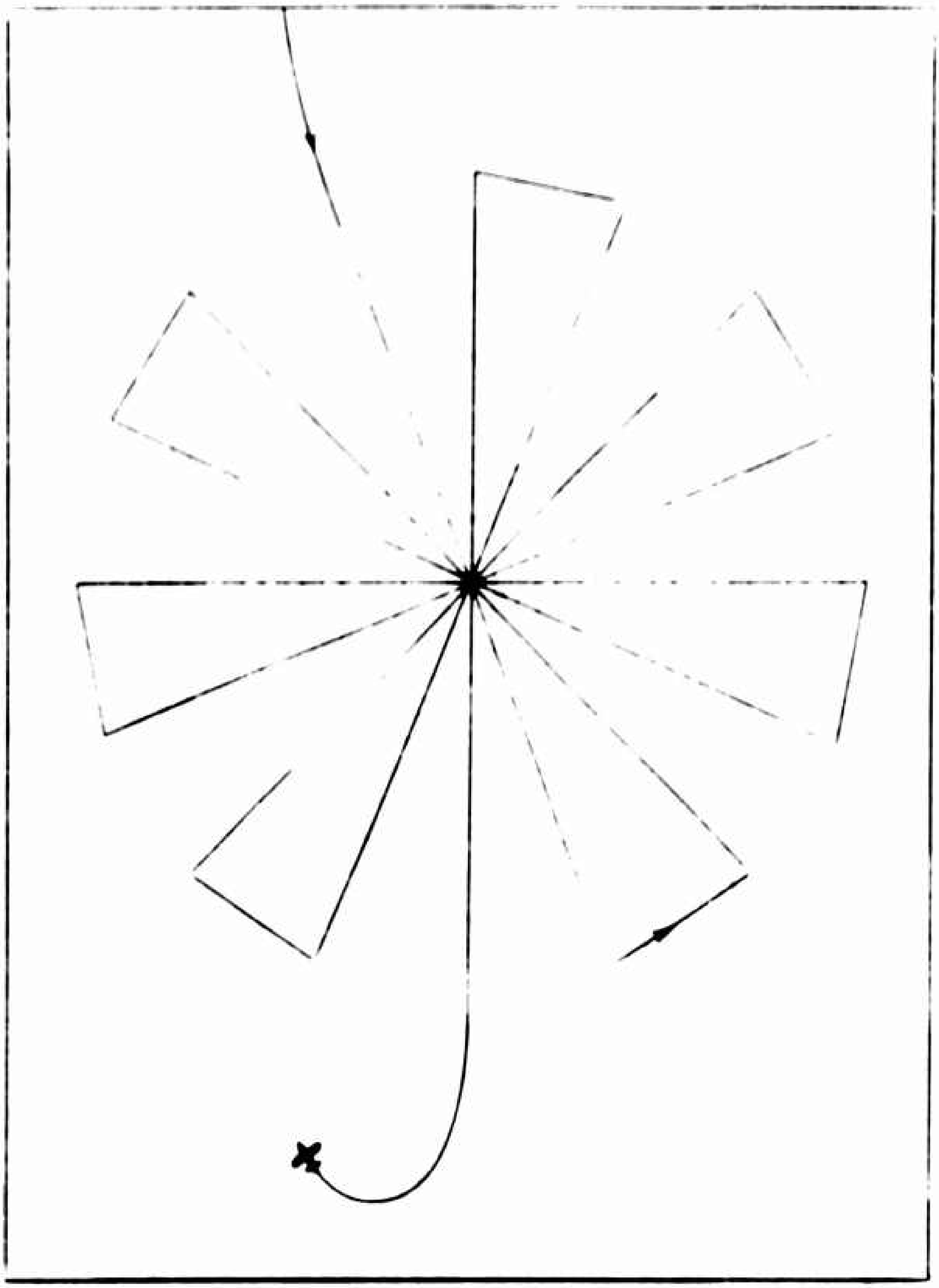
The total effort expended in a sector search can be expressed by the integral

$$\bar{E} = \int_0^{\infty} \phi(r)\, 2\pi r\, dr$$

where R is search radius

r is the distance from the center of the search

Figure 10. The Sector Search



$\varphi(r)$ is the search effort density at some distance r.

This density function $\varphi(r)$ is simply W times the number of paths which intersect a circle of radius r, multiplied by dr to give total path length between r and r+dr, and then divided by the area between r and r+dr. Thus

$$\varphi(r) = \frac{Wn\,dr}{2\pi r\,dr} = \frac{Wn}{2\pi r} \qquad (19)$$

Then,

$$E = WL = \int_0^\infty \frac{Wn}{2\pi r}\,2\pi r\,dr = WnR \qquad (30)$$

and,

$L=nR$

as expected.

Here n is the number of 'spokes' produced, or twice the number of complete sweeps across the circle. This density function is illustrated in Figure 11.

B. PATTERN ERROR

There will always be some error in flying any search pattern, which should be taken into account for the sector search. The navigation error of the searcher has already been taken into account when computing the Total Probable Error of Position. The <u>pattern error</u>, however, can be

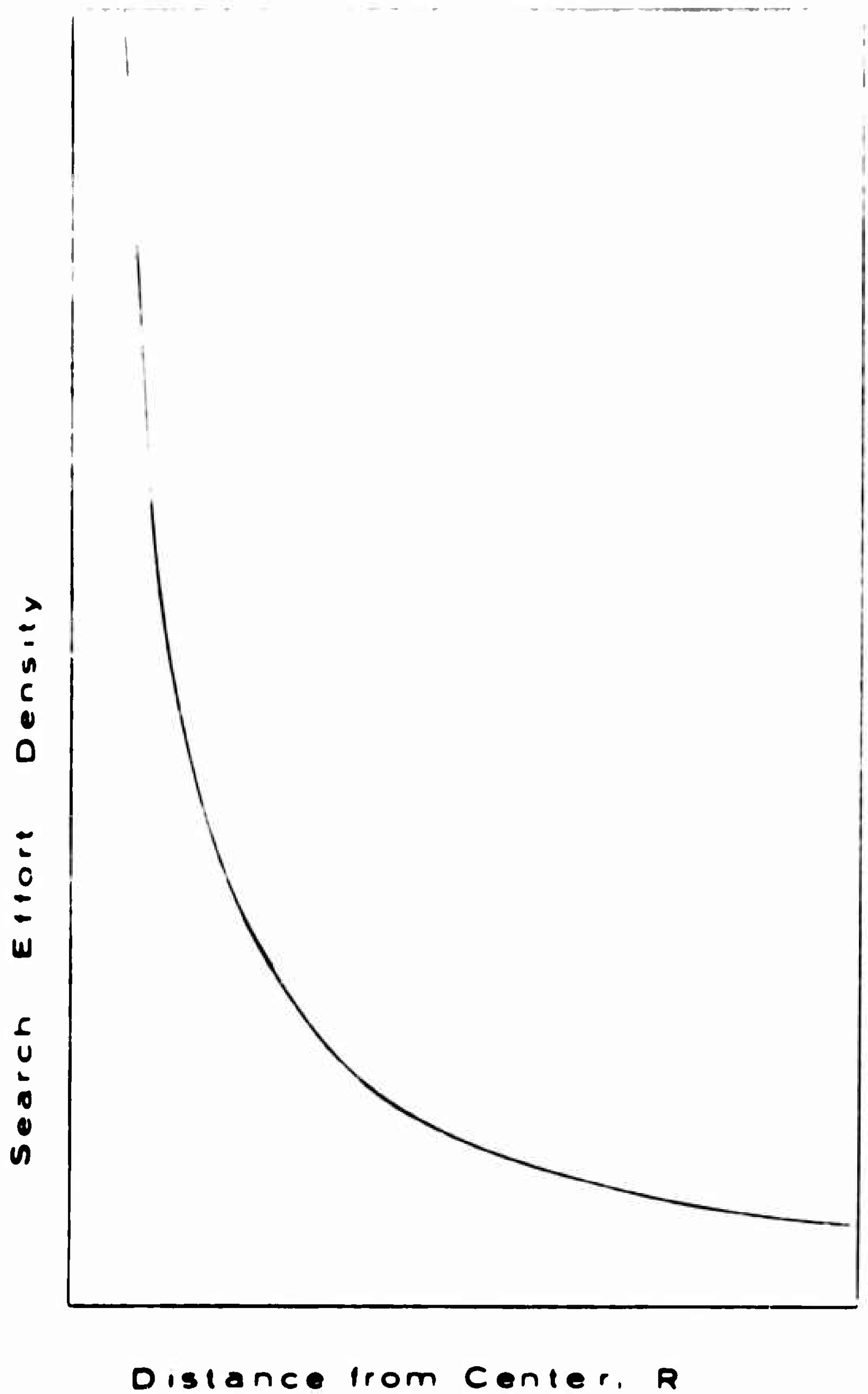


Figure 11. Search Effort Density in a Perfectly Navigated Sector Search.

different from this navigation error. Whereas navigation error considers only the searcher's ability to find the datum point in order to define the search area, pattern error, as it is used here, describes his flying error within the area. If, once the searcher finds what he thinks to be datum, he drops a smoke float or some other marking device, then his pattern error will be much smaller than his navigation error. Conversely, if when arriving in the search area he stops refering to his navigation aids and relies thenceforth on dead reckoning only, his pattern error will be greater than his navigation error.

Although by its nature, a flying error is bivariate (like the error of target position) a simplification was made. Since the pilot is flying long sweeps which have their endpoints relatively far away from the area of concern (the center of the area), only his lateral position error (which is univariate) was considered.

It was assumed for this analysis that the lateral component of pattern error is nearly normal, and that it can somehow be calculated or estimated.

The expression for the total effort expended in flying the spokes of a sector search is

$$E = 2Wn \int_0^R \int_0^{\frac{\pi}{2}} \frac{1}{\sqrt{2\pi}\,\sigma_p} e^{-\frac{r^2 \sin^2 \alpha}{2\sigma_p^2}} r\,dr\,d\alpha \qquad (31)$$

($r \sin\alpha$ = Lateral range)

(σ_p = σ Lateral pattern error)

The derivative of this expression with respect to r was used as the search effort density function for a sector search with pattern error.

$$\varphi(r) = \frac{2Wn}{\pi}\int_{\alpha=0}^{\pi/2} \frac{1}{\sqrt{2\pi}\,\sigma_r}\, e^{-\frac{r^2 \sin^2 \alpha}{2\sigma_r^2}}\, d\alpha \qquad (32)$$

For the analysis this basic density function was computed with sweep width, standard deviation of pattern error, and number of spokes all equal to 1. To find the density function for any particular set of parameters, the density is multiplied by W and n, and the horizontal scale is multiplied by the standard deviation of the pattern error.

C. OPTIMUM SECTOR SEARCH

The plot of this density function is found in Figure 12. An inspection of this plot will show that it is close to a quadratic function out to r = 3 standard deviations. Since Koopman's ideal search is a quadratic, some guidance was provided as to the optimum radius for the sector search, based on the pattern error. It was then necessary to adjust the number of spokes to arrive at the ideal effort expenditure to match this radius. Koopman's ideal search effort density is a function of search radius and target's position error:

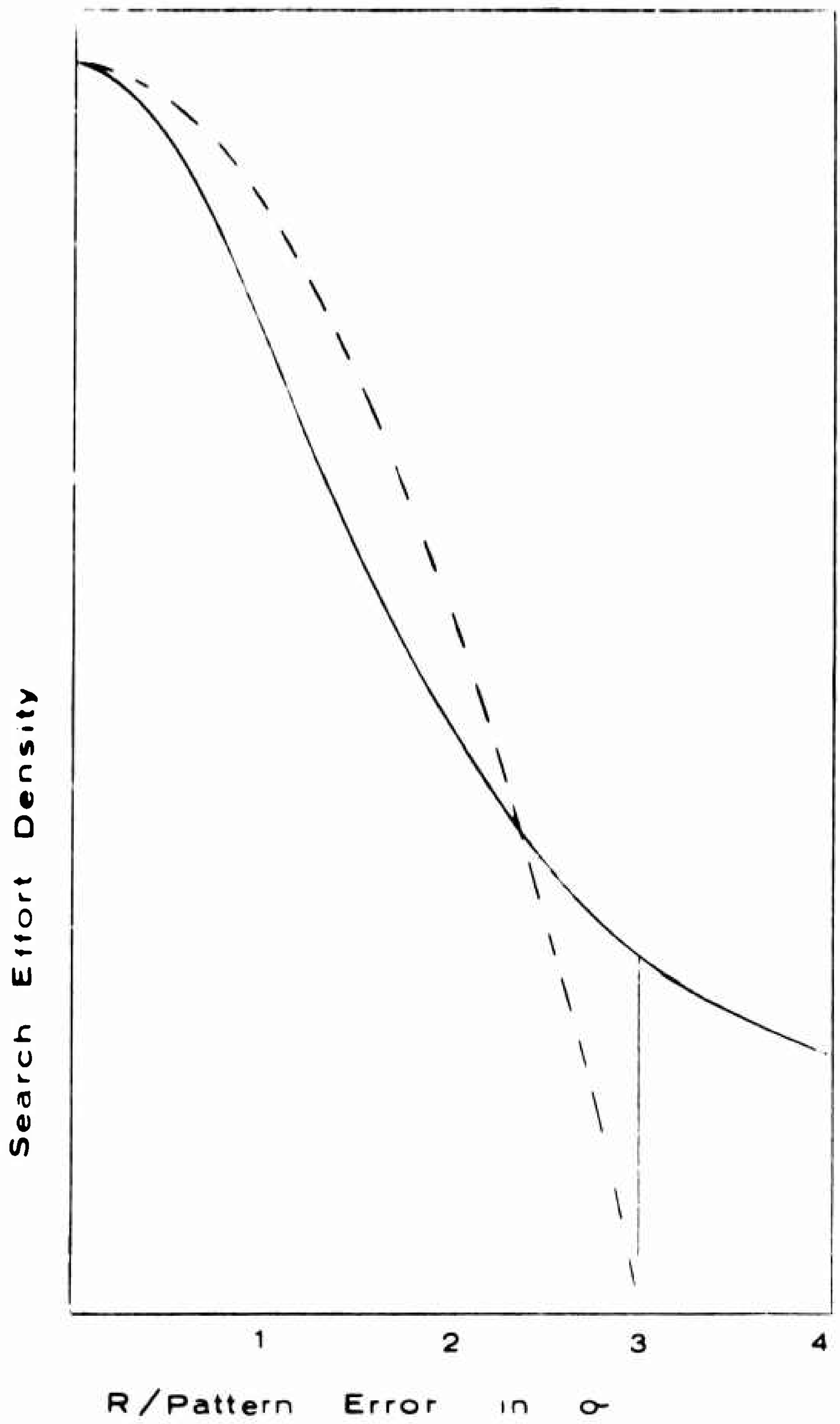


Figure 12. Search Effort Density in a Sector Search with Pattern Error.

$$\varphi(x,y) = \begin{cases} \dfrac{a^2 - r^2}{2\sigma^2} & r \le a \\ 0 & r > a \end{cases}$$

and the radius is a function of target position error and available effort:

$$a = \left[\frac{4\sigma^2 E}{\pi}\right]^{\frac{1}{4}}$$

Solving for effort, E:

$$E = \frac{a^4 \pi}{4\sigma^2} = WL$$

However, in the case of the sector search, L, the number of miles flown, is simply the number of spokes, n, times the radius. The chords flown at the perimeter are disregarded in this analysis:

$$L = a \times n$$

Substituting, and solving for n:

$$n = \frac{a^3 \pi}{4\sigma^2 W}$$

Ideally, then, since the optimum a is known to be

close to three standard deviations:

$$\boxed{m = \frac{27\,\sigma_p^{3}\,\pi}{4\,\sigma^{2}\,W}} \qquad (33)$$

or, when all errors are expressed as probable errors,

$$C_p = .67\,\sigma_p$$

$$C = 1.18\,\sigma$$

$$\boxed{m = \frac{0.95\,C_p^{3}}{W\,C^{2}}} \qquad (34)$$

Table 1 is a tabulation of this function for various conditions of total probable error of position c, and pattern error. The n derived from the table must be divided by sweep width W to obtain number of spokes.

From the example of the sunken fishing boat, c = 31.9 and W = 10.0 miles. If the searcher's pattern error were 13 miles, then search radius R would equal 58.5 miles.

Interpolating in the table, n = 100, then

Number of spokes = 100/10 = 10

and the angle between adjacent search legs = 360/10 = 36 degrees.

Total search miles flown would be

10 X 58.5 = 585

plus the amount of flying at the perimeter (in order to fly the pattern, the aircraft must traverse a distance somewhat less than one-half the circumference of the area):

585 + 58.5 X π = 585 + 184 = 770 miles.

This table for sector search will not be useful until an accurate means of predicting pattern error is found. The function given in (34) is extremely sensitive to pattern error, and thus accuracy for this parameter is required to use the table.

Even if it is not actually used to determine the parameters of a sector search, the table does serve to

SECTOR SEARCH

TABLE OF OPTIMUM RADIUS AND NUMBER OF SEARCH LEGS

PATTERN ERROR	OPTIMUM RADIUS	POSITION ERROR, C 5	10	15	20	25	30	35	40	45	50
				N X W							
1.0	4.5	1	0	0	0	0	0	0	0	0	0
2.0	9.0	14	3	1	0	0	0	0	0	0	0
3.0	13.5	50	12	5	3	2	1	1	0	0	0
4.0	18.0	119	29	13	7	4	3	2	1	1	1
5.0	22.5	233	58	25	14	9	6	4	3	2	2
6.0	27.0	403	100	44	25	16	11	8	6	4	4
7.0	31.5	641	160	71	40	25	17	13	10	7	6
8.0	36.0	957	239	106	59	39	26	19	14	11	9
9.0	40.5	1363	340	151	85	54	37	27	21	16	13
10.0	45.0	1970	467	207	116	74	51	38	29	23	18
11.0	49.5	2489	622	276	155	99	69	50	38	30	24
12.0	54.0	3231	807	359	201	129	89	65	50	39	32
13.0	58.5	4109	1027	456	256	164	114	83	64	50	41
14.0	63.0	5132	1283	570	320	205	142	104	80	63	51
15.0	67.5	6312	1578	701	394	252	175	128	98	77	63
16.0	72.0	7660	1915	851	478	306	212	156	119	94	76
17.0	76.5	9188	2297	1020	574	367	255	187	143	113	91
18.0	81.0	10907	2726	1211	581	436	302	222	170	134	109
19.0	85.5	12829	3207	1425	801	513	356	261	200	158	128
20.0	90.0	14962	3740	1662	935	598	415	305	233	184	149

Table 1. Optimum Sector Search. Divide quantity in "N X W" table by Sweep Width to obtain number of search legs.

illustrate that accurate navigation does not necessarily produce the optimum sector search, and that only under the unusual conditions of an extremely accurate estimate of target position is it desireable to reduce pattern error. On the contrary, in most instances, effectiveness may be enhanced by <u>increasing</u> pattern error.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. THE SEARCH PLANNING PROGRAM

It is recommended that the Coast Guard begin immediately to make full use of the Search Planning Program now operational and undergoing testing at the Fleet Numerical Weather Central, Monterey. A guide for users of this program is included as Appendix A.

1. Precautions

The following cautions are appropriate for users of the information provided by this program.

a. Region of Validity.

Because the weather data points used in this program are approximately 200 miles apart, drift calculations provided for areas within 100 miles of shore should be double-checked by hand before using. If hand calculations produce a larger value for total drift, then the hand-calculated answers should be used in lieu of the computer solution.

b. Time of Datum

Weather predictions in the format required for this program are not produced by the Weather Facility for more than 48 hours in advance. Accordingly, users should

avoid requesting plots for time periods beyond 36 hours from the time the request is submitted. If a plot is requested which is later in time than the last computed weather, the information will be provided for that plot and a caution statement will appear in the message reply.

c. Numbers of Initial and Datum Positions

No more than nine initial positions may be entered, and no more than nine datum times will be calculated, in any one run of the program.

The user is encouraged to request whatever number of datum points may be useful to him. Thus if a search is planned for 0800Z, the search planner may wish to request additional data for target position at 1000Z, 1200Z, 1400Z, and 1600Z.

2. Leeway

It is suggested that further experimentation be done in the area of survivor craft leeway to determine the general shape of the leeway function. It is expected that this shape will be close to that of the liferaft drift tables, and to the formula of Witting given in Ref.3.

$$V = k\sqrt{Wind} \qquad (35)$$

and which is used in the time-sharing version of the program for all leeway. This same function is used in both versions to approximate liferaft leeway.

When better data is available, the program at Fleet Numerical can be changed to accomodate the curved leeway function.

3. Testing

It is suggested that a rigorous program of testing and evaluation of the results of the Search Planning Program be initiated. If the program proves to be more accurate than other methods, its contribution to the search planning process, and to oceanographic research in general, will be substantial.

4. Operational Use in the Coast Guard

Although the program will be available to the Coast Guard via the facilities of the Fleet Numerical Weather Central, there are further possible advantages of such a program which are not available through these facilities.

a. Optimum Search Areas

The computer method of solving for optimum searches shown in part IV of this thesis could be added to the Search Planning Program.

b. Other Applications

Computation of on-scene aircraft endurance, time enroute search areas, division of search area among different search units, maximum rescue coverage intercepts, fixes from radio direction finder bearings, and many other calculations familiar to search planners could all be available instantly from a remote computer terminal.

The Coast Guard Amver computer center at Governor's Island New York regularly receives weather data by wire from Fleet Numerical Weather Central which is used to produce weather maps. The fields required for the Search Planning Program could also be transmitted to a central Coast Guard computer facility. Remote terminals connected to this facility and installed in Rescue Coordination Centers (RCC's) could provide the output from this program, Amver surface picture plots, and other useful data directly to search planners.

B. DETERMINATION OF SEARCH AREAS

It is recommended that the findings of parts IV and V of this thesis be evaluated by the Coast Guard and applicable portions be included in the National Search and Rescue Manual.

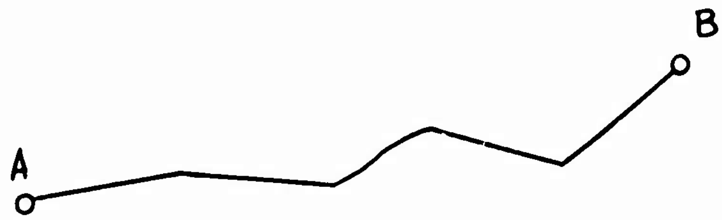
C. FUTURE RESEARCH

There are many unexplored areas in the field of Search Planning in which further research may yield valuable results.

1. The Trackline Search

Although the type of point-datum search presented in parts IV and V are computed in two dimensions, there are times when the target's distribution is centered on a line of position (or trackline), which presents a problem

essentially one dimensional in nature.



If a boat departs point A intending to follow a certain track AB to point B, and does not arrive at point B, and if no other information is available as to his probable position, a one-dimensional or trackline search problem is presented.

a. Partial Solution

Assuming that it is decided to begin the searching efforts by executing just one sweep along the length of the trackline, what is the probability that the target will be located? The following analysis is for the inverse cube law of detection.

Given the standard deviation of the target's error of position σ, and given sweep width, W, where

$$W = 2\sqrt{2\pi m} \tag{36}$$

Solving for m, which includes visibility and other factors,

$$m = \frac{W^2}{8\pi} \tag{37}$$

The probability of detecting a uniformly distributed target is

$$d(x) = 1 - e^{-\frac{m}{x^2}} \tag{38}$$

$$= 1 - e^{-\frac{W^2}{4\pi x^2}} \tag{39}$$

Introducing a new variable, $\beta = \frac{2\sigma}{W}$

$$d(x) = 1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}} \tag{40}$$

The probability that the target is located at some distance x from the trackline may be assumed to be

$$p(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{x^2}{2\sigma^2}} \tag{41}$$

Thus, the probability of detecting this target is

$$P = \int_{-\infty}^{+\infty} \left(1 - e^{-\frac{\sigma^2}{\beta^2 \pi x^2}}\right)\left(\frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{x^2}{2\sigma^2}}\right) dx \tag{42}$$

$$= 1 - \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\left(\frac{x^2}{2\sigma^2} + \frac{\sigma^2}{\beta^2 \pi x^2}\right)} dx \tag{43}$$

Introducing $\gamma = \frac{x}{\sqrt{2}\,\sigma}$, $d\gamma = \frac{1}{\sqrt{2}\,\sigma} dx$

$$P = 1 - \sqrt{2} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi}} e^{-\left(\gamma^2 - \frac{1}{2\pi \beta^2 \gamma^2}\right)} d\gamma \tag{44}$$

which has the solution

$$P = 1 - e^{-\frac{\sqrt{2}}{A}} = 1 - e^{-\frac{W}{\sqrt{2}\,\sigma}} \qquad (45)$$

b. General Solution

The solution for probability P of detecting a target on a trackline search for more than one sweep involves a more complicated expression, one which does not lend itself to such a simple solution. Since a trackline search is executed one sweep at a time, a general solution for the optimum distance of each sweep from the trackline is indicated, and should be the subject of further study.

2. <u>Optimum Search Speed</u>

The Search and Rescue Manual prescribes a "moderate" speed for searching. Koopman's formula for sweep width, from (9) gives

$$W = \sqrt{\frac{2kh}{\omega}}$$

This indicates that sweep width is inversely proportional to the square root of the relative speed of the target, w. When search speed is very large in comparison to target speed, w takes on the value of the searcher's speed. As w increases, however, the amount of search path length L that can be covered in a certain period of time increases proportionally: $L = K_1 \omega$

It follows that the amount of search effort, W x L, that can be effected by a certain number of aircraft in a fixed period of time increases as the square root of search speed:

$$\frac{W}{S} = K_2 = \frac{WL}{A}$$

$$A = \frac{WL}{K_2}$$

$$\frac{WL}{K_2} = A = \frac{\sqrt{\frac{2kh}{\omega}} \quad K_1 \omega}{K_2} = \frac{K_1}{K_2} \sqrt{2kh\omega} \qquad (47)$$

It may be argued, then, that when time is a factor, such as where persons in distress may not survive for long periods of time, searching should be accomplished at the highest speed practicable. In addition, since the coverage of a designated search area will take less time at a higher speed, lookouts may encounter less fatigue, and the effectiveness of the search may be enhanced.

D. CONCLUSION

In conclusion, there is a need for more scientific research in the practical aspects of search planning, and a corresponding need for the education of search planners in the fields of probability and search theory.

APPENDIX A

USER'S GUIDE TO SEARCH PLANNING PROGRAM

1. Description

The MONTEREY SEARCH PLANNING PROGRAM is a computer program which solves open ocean drift plotting problems, and provides datum, minimax datum, Total Probable Error of Position, and Search Radius for both simple and complex searches. The use of this program is available upon request, on a test basis, to all Rescue Coordination Centers through the facilities of the U.S. Navy Fleet Numerical Weather Facility, Monterey, California.

2. Input Data

a. Leeway Code

For this program, leeway is expressed as a two-digit code as shown in Table 1.

Leeway Code

00	No Leeway
10	Liferaft with Drogue
11	Liferaft without Drogue
12	Liferaft (Minimax)
13 - 19	Downwind drift (minimax) Minimum = 1% of wind velocity Maximum = Second digit as % of Wind Velocity.
20,30,etc.	Downwind drift at 2%,3%, etc. of the wind velocity
21 - 99	Minimax drift at some fixed percent of wind velocity equal to first digit; Deflection to the right and left of the wind line equal to 10 degrees times the second digit.

Table 1. Leeway Code

Example: 43 = 4% of wind velocity

± 30 degrees off wind line

b. Number of Starting Points

The number of starting (or distress) positions must be indicated. The maximum number that can be supplied is <u>nine</u>.

c. Number of Datum Times

The number of datum (or search) times for which plots are requested must be supplied. The maximum number of these is also <u>nine</u>.

d. Starting Point Data

Starting positions must be entered in chronological order and each point must be <u>fully</u> identified by:

(1) Date-time group (time zone Zulu)

(2) Month

(3) Latitude and Longitude in degrees and minutes. Tenths of minutes must be specified. The number of these starting positions must agree with paragraph 2.a.

e. Datum Times

Complete Date-time group (including month) for each datum time must be supplied, in chronological order. The number of these datum times must agree with paragraph 2.c.

f. Last Known Position

This is the last <u>known</u> position of the search object (see Para. 611, National Search and Rescue Manual) to be

used in computing DR position error. This position must be complete with degrees, minutes, and tenths of minutes. If DR position error is not applicable, enter one of the initial positions from 2.d.

g. Error Factors

These factors must all be specified to at least one decimal place, in the following order:

(1) Probable navigation error of search craft.

(2) Initial probable error in position of the search object.

(3) Percent of DR distance to be applied as DR error (See Para. 611, National Search and Rescue Manual). Enter 0.0 if not applicable.

h. Search Designators

These should be one-digit numbers, from 0 to 5, which describe which Safety Factors are to be applied to the Total Probable Error of position for each datum time. One digit <u>must</u> be supplied for each datum time.

0 No search radius is to be computed for that datum time

1,2,3,4,5 The Safety Factor corresponding to search 1,2,3,4, or 5 is to be applied.

3. <u>Message Request Format</u>

A message request to Fleet Numerical Weather Central

will insure that the data is entered correctly into the computer:

FM CEA
TO FLENUMWEACEN MONTEREY
BT
UNCLAS
DISTRESS HOMEY 65 OVERDUE

1. REQUEST SAR PLOT.
2. DATA:
   A. 12/2/3//
   B. Ø3Ø9ØØZ AUG,352Ø.ØN,Ø5216.5W/Ø312ØØZ AUG, 36ØØ.ØN,Ø514Ø.ØW//
   C. Ø316ØØZ AUG/Ø322ØØZ AUG/Ø4Ø2ØØZ AUG//
   D. 35ØØ.ØN,Ø514Ø.ØW/5.Ø/1Ø.Ø/Ø.1Ø/1Ø2//

This sample message requests a minimax plot of a liferaft from two initial positions, with data requested for three different times (para. 2.A.). The initial positions and date-time groups are given in para. 2.B. (note that 2 digits are used to express degrees latitude and 3 digits are used for degrees longitude).

Paragraph 2.C. gives the date-time groups of the datum times. Paragraph 2.D. gives the last known position, error factors, and search designators. for this example, the first search is to be computed for 031600Z and a second

search for 040200Z. No search radius is to be computed for 032200Z; positions and position errors will still be provided.

4. Caution: Offshore Regions

This program is designed primarily for open ocean search; when data is supplied for water areas within 100 miles from shore, answers should be checked by hand calculations. Requests for SAR Plots within 10 miles from shore should be avoided.

Weather information used in this program is applicable to the Northern Hemisphere only.

EXAMINATION OF CRITERIA FOR REPEATED SEARCHES

INVERSE CUBE LAW, PARALLEL SWEEPS FOR PROBABILITY OF DETECTION

LT J. F. CISCENZA, USCG

SWEEP WIDTH SET TO 0.04 TIMES PROBABLE ERROR

SEARCH NUMBER	OPTIMUM RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
MILES FLOWN/PROBABLE ERROR=114.2, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 4.8										
1	[illegible]	0.03	[illegible]	[illegible]	0.512	1.10	0.04	0.647	0.790	0.511
MILES FLOWN/PROBABLE ERROR=241.7, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 10.2										
2	1.64	0.04	0.769	0.766	0.604	1.60	0.04	0.764	0.790	[illegible]
MILES FLOWN/PROBABLE ERROR=377.6, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 16.0										
3	2.07	0.04	0.847	0.759	0.643	2.00	0.04	0.915	0.790	[illegible]
MILES FLOWN/PROBABLE ERROR=[illegible], TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 21.2										
4	2.43	0.04	0.880	0.740	0.651	2.30	0.04	0.809	0.790	0.639
MILES FLOWN/PROBABLE ERROR=590.0, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 25.0										
5	[illegible]	0.04	[illegible]	0.704	0.631	2.50	0.04	0.742	0.790	0.579

REDUCE EFFORT 50%

SEARCH NUMBER	OPTIMUM RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS	STANDARD RADIUS	TRACK SPACING	PROBABILITY TARGET IN AREA	PROBABILITY OF DETECTION	PROBABILITY OF SUCCESS
MILES FLOWN/PROBABLE ERROR= 57.1, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 2.4										
1	[illegible]	[illegible]	0.459	0.701	0.329	1.10	0.08	0.647	0.469	0.304
MILES FLOWN/PROBABLE ERROR=120.9, TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 5.1										
2	[illegible]	[illegible]	0.651	0.655	0.427	1.60	0.08	0.828	0.469	0.398
MILES FLOWN/PROBABLE ERROR=[illegible], TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 8.0										
3	[illegible]	[illegible]	0.744	0.636	0.473	2.00	0.08	0.907	0.469	0.424
MILES FLOWN/PROBABLE ERROR=[illegible], TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 10.6										
4	[illegible]	[illegible]	[illegible]	0.615	0.488	2.30	0.08	0.935	0.469	0.430
MILES FLOWN/PROBABLE ERROR=[illegible], TOTAL EFFORT (W X MILES FLOWN/PROBABLE ERROR) = 12.5										
5	[illegible]	[illegible]	[illegible]	0.580	0.475	2.50	0.08	0.940	0.469	0.440

```
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
C
C          MONTEREY SEARCH PLANNING PROGRAM
C
C
C       PROGRAMMER:  LT J. H. DISCENZA, USCG
C        NAVAL  POSTGRADUATE SCHOOL, MONTEREY, CALIFORNIA
C
C
C       PURPOSE: TO PROVIDE THE SEARCH AND RESCUE MISSION COORDINATOR
C       WITH A COMPUTER AID IN PLANNING AN OCEAN SEARCH.
C       REFERENCES:
C            (1) NATIONAL SEARCH AND RESCUE MANUAL, CG-308
C            (2) W.E. HUBERT, T.LAEVASTU, SYNOPTIC ANALYSIS AND
C             FORECASTING OF SURFACE CURRENTS,  JUNE 1967
C            (3) W.H. RICHARDSON, EMPIRICAL SWEEP WIDTH ANALYSIS,
C            SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1968
C
C
C
C
C       DISCUSSION:
C            THE BASIC PLANNING PROCESS IN THE PROGRAM IS ONE OF
C       AN OPEN OCEAN SEARCH FOR A DISTRESSED CRAFT WHERE SOME SOME
C       BEGINNING POINTS ARE KNOWN, AND WHERE A DATUM (OR DATUM POIN
C       TS ) ARE REQUIRED FOR SOME FUTURE TIME.  ALTHOUGH THE PROGRAM
C       IS SPECIFICALLY DESIGNED TO WORK WITH WEATHER DATA FROM A
C       TAPE OR DISK DATA BANK OF WEATHER INFORMATION, PROVISION IS
C       MADE FOR OPERATOR ENTRY OF WEATHER INFORMATION IF SUCH DATA
C       BANK OF WEATHER IS NOT AVAILABLE.
C       ENTERING ARGUMENTS:
C            IX:    CLASS NUMBER OF SEARCH OBJECT - RELATES TO SIZE
C                  AND DRIFTING CHARACTERISTICS
C            DESC:    ALPHAMERIC DESCRIPTION OF SEARCH OBJECT
C            M1:    THE NUMBER OF STARTING POINTS FOR COMPUTATION
C                  OF DATUM
C            A1:    THE DATES AND TIMES OF THE STARTING POSITIONS
C            LAD,YLA,D:    LATITUDE OF STARTING POSITIONS
C            LOD,YLO,H:    LONGITUDE OF STARTING POSITIONS
C            M2:    NUMBER OF TIMES DATUM IS TO BE COMPUTED
C            T2:    TIMES FOR WHICH DATUM IS TO BE COMPUTED
C       OUTPUTS:
C            LAF, FLA, DE:    LATITUDE OF DATUM POINTS
C            LCF, FLO ,HE:    LONGITUDE OF DATUM POINTS
      WRITE(6,100)
 1001 FORMAT('1    MONTEREY SEARCH PLANNING PROGRAM'//' ENTERING ARGUMEN
     1TS'//' CLASS',2I2)
```

```
100   FORMAT('    MCNTEREY SEARCH PLANNING PROGRAM')
      COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,O,
     1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
     2DESC(15),FLA(9,18),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,
     3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
      INTEGER T2(3,9),T3(3),O(9),TAP
      INTEGER A1(3,9)
      INTEGER LAF(9,9),LOF(9,9)
      TAP=0
      P=3.14159/180.
      WRITE(6,101)
101   FORMAT(' ENTER LEEWAY CODE, 1 BLANK, THEN DESCRIPTION')
      READ(5,200)IX1,IX2,LEVEL,DESC
 200  FORMAT(2I1,I1,15A4)
      DO 11 I=1,9
  11  O(I)=0
      IF(LEVEL.EQ.0) GO TO 16
      IF(LEVEL.GT.5)GO TO 17
      IF(LEVEL.EQ.5)GO TO 18
      IF(LEVEL.EQ.4)GO TO 20
      DO 12 I=1,LEVEL
  12  O(I)=1
      GO TO 16
  18  DO 19 I=1,9
  19  O(I)=1
      GO TO 16
  20  DO 21 I=1,[illegible]
  21  O(I)=[illegible]
      GO TO 16
  17  DO 22 I=1,3
  22  O(I)=1
      O(LEVEL)=1
      O(LEVEL-3)=1
  16  CONTINUE
      IF(O(1).EQ.1)WRITE(8,1001)IX1,IX2
      IF(O(1).EQ.1)WRITE(8,1011)DESC
1011      FORMAT(' DESC: ',15A4)
      WRITE(6,103)
 103  FORMAT(' HOW MANY STARTING POINTS WILL BE ENTERED?')
      READ(5,202)M1,DUMI,DUMJ
202   FORMAT(I1,2F4.0)
      IF(O(1).EQ.1)WRITE(8,1002)M1
1002  FORMAT(' NUMBER OF STARTING POINTS, M1= ',I1)
      IF(IX2.GT.0)M4=2*M1
      CD1=+IX2*10
      CD2=-IX2*10
      CV1=FLOAT(IX1)/25.
      CV2=FLOAT(IX1)/25.
```

```
      CV3=0.
      CV4=0.
      IF(IX1.NE.1)GO TO 10
      CD1=0.
      CD2=0.
      IF(IX2.GT.2)GO TO 2
      CV1=.098
      CV2=.226
      CV3=0.
      CV4=0.
      IF(IX2.LT.2)M4=M1
      IF(IX2.EQ.1)CV1=CV2
      IF(IX2.EQ.1)CV3=CV4
      GO TO 10
    2 CV2=FLOAT(IX2)/100.
   10 CONTINUE
      IF(O(1).EQ.1)WRITE(8,1003)M4
 1003 FORMAT(' NUMBER OF SEPARATE TRACKS TO BE PLOTTED,M4=', I2)
 1015 FORMAT(' DIVERGENCE OF TRACKS=+',F4.1,' AND',F5.1)
      IF(O(2).EQ.1)WRITE(8,1015)CD1,CD2
 1016 FORMAT(' LEEWAY=',F7.4,'+',F7.4,'X WIND')
      IF(O(2).EQ.1)WRITE(8,1016)CV3,CV1
      IF(O(2).EQ.1)WRITE(8,1016)CV4,CV2
   33 WRITE(6,106)
  106 FORMAT(' LIST CHRONOLOGICALLY: STARTING TIMES AND POSITIONS, EX:')
      WRITE(6,107)
  107 FORMAT(' 070930Z MAR,3822.5N,06806.5W ')
      READ(5,203)((A1(I,J),I=1,3),TZ(J),MON(J),LAD(J),YLA(J),D(J),LOD(J)
     1,YLO(J),H(J),J=1,M1)
      IF(O(1).EQ.1)WRITE(8,1010)
 1010 FORMAT(' STARTING TIMES AND POSITIONS ENTERED:')
      DO 40 J=1,M1
   40     A1(1,J)=JULIAN(MON(J),A1(1,J))
      IF(O(1).EQ.1)WRITE(8,1017)
      IF(O(1).EQ.1)WRITE(8,1023)((A1(I,J),I=1,3),LAD(J),YLA(J),D(J),LOD(
     1J),YLO(J),H(J),J=1,M1)
 1023 FORMAT(3I2,I12,'-',F5.2,A1,I5,'-',F5.2,A1)
 1017 FORMAT(' DATE-TIME      LATITUDE    LONGITUDE')
  203 FORMAT(3I2,A1,1X,A3,1X,I2,F4.1,A1,1X,I3,F4.1,A1)
      CALL NSEW
      IF(O(2).EQ.1)WRITE(8,1004)CHECK
 1004 FORMAT(' ANSWER TO CHECK: ',A1)
      DATA WRONG/1HN/
      IF(CHECK.EQ.WRONG)GO TO 33
      WRITE(6,108)
  108 FORMAT(' ENTER NUMBER OF TIMES DATUM IS TO BE COMPUTED NOW:')
      READ(5,204)M2,TAP
  204 FORMAT(2I1)
```

```
      IF(O(1).EQ.1)WRITE(8,1005)M2
 1005 FORMAT(' DATUM TO BE COMPUTED ',I1,' TIMES.')
   34 WRITE(6,109)
  109 FORMAT(' ENTER THESE DTGS.  EX:020900 MAR,031030 MAR')
      READ(5,205)((T2(I,J),I=1,3),MON(J),J=1,M2)
  205 FORMAT(9(3I2,1X,A3,1X))
      IF(O(1).EQ.1)WRITE(8,1006)((T2(I,J),I=1,3),J=1,M2)
      DO 41 J=1,M2
   41    T2(1,J)=JULIAN(MON(J),T2(1,J))
 1006 FORMAT(' THESE TIMES ARE ',9(3I2,1H,))
      CALL WXCOMP
      CALL DATUM
      CALL RADII
      DO 61 J=1,M2
      IF(M4.EQ.M1)GO TO 62
      WRITE(6,133)
  133 FORMAT(' THE FOLLOWING ARE THE MINIMAX DATUM POINTS FOR THE')
      GO TO 63
   62 WRITE(6,130)
  130 FORMAT(' THE FOLLOWING ARE THE DATUM POINTS FOR THE')
   63 WRITE(6,131)T2(2,J),T2(3,J)
  131 FORMAT(I3,1H:,I3' SEARCH:')
      WRITE(6,132)(LAF(J,I),FLA(J,I),DE(J,I),LOF(J,I),FLO(J,I),HE(J,I),
     1C(J,I),RADIUS(J,I),(WIND(MM,I,J),MM=1,2),I=1,M1)
  132  FORMAT(2(I3,'-',F4.1,A1,4X),'POS. ERROR:',F6.1,', RADIUS:'F6.1' M
     1ILES:'/10X,' WIND',F5.1,'KTS  FROM',F5.0)
      IF(RADIUS(J,I).EQ.0.)GO TO 61
      WRITE(6,134)
      READ(5,135)ANS
      IF(ANS.EQ.WRONG)GO TO 61
      WRITE(6,136)
      READ(5,137)ALT
      WRITE(6,138)
      READ(5,137)VIS
      WRITE(6,139)
      READ(5,137)VLEN
      WRITE(6,140)
      READ(5,137)CLOUDS
      WW=SWIDTH(VLEN,VIS,ALT,WIND(1,I,J),CLOUDS)
      WRITE (6,141)WW
  134 FORMAT(' SWEEP WIDTH?  Y OR N')
  135 FORMAT(A1)
  136 FORMAT(' ENTER SEARCH ALTITUDE (EX:800.)')
  137 FORMAT(F10.0)
  138 FORMAT(' ENTER VISIBILITY IN MILES (EX:10.0)')
  139 FORMAT(' ENTER BOAT LENGTH IN FEET  (EX:36.0)')
  140 FORMAT(' ENTER CLOUD COVER IN FRACTION (EX: 0.9)')
  141 FORMAT(' SWEEP WIDTH=',F10.1,' MILES.')
```

```
 61   CONTINUE
      WRITE(6,999)
      WRITE(6,998)DESC
 999  FORMAT(' GOOD LUCK ON YOUR SEARCH  LET ME KNOW IF YOU FIND')
 998  FORMAT(' THE',15A4////)
      STOP
      END
C-----------------------------------------------------------------------
C
C
C                   SUBROUTINE NSEW
C
C           PROGRAMMER: LT J. H. DISCENZA, USCG
C
C
C                THIS SUBROUTINE  CONVERTS LATITUDE AND LONGITUDE AS
C           EXPRESSED IN "NORTH" AND "SOUTH" TO ALGEBRAIC (+ OR -)
C           QUANTITIES.   IN ADDITION IT READS THE ALGEBRAIC QUANTITIES
C           BACK TO THE OPERATOR FOR HIM TO DOUBLE CHECK.
C
C           ENTERING ARGUMENTS:
C                LAD,YLA,D:    LATITUDES (D=N,S)
C                LCD,YLO,H:    LONGITUDES (H=E,W)
C                M1:    THE NUMBER OF POSITIONS TO BE CONVERTED
C           OUTPUTS:
C                LAD,YLA:    ALGEBRAIC VERSION OF LATITUDE
C                LCD,YLO:    ALGEBRAIC VERSION OF LONGITUDE
C                CHECK:    A "Y" OR "N" ANSWER FROM THE OPERATOR WHICH
C                     INDICATES WHETHER THE LIST OF LATITUDES AND
C                     LONGITUDES PRODUCED ARE CORRECT.
C


      SUBROUTINE NSEW
      COMMON LAD(9),YLA(9),D(9),LCD(9),YLO(9),H(9),M1,CHECK,O,
     1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
     2DESC(15),FLA(9,18),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,
     3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
      INTEGER T2(3,9),T3(3),O(9)
      INTEGER A1(3,9)
      INTEGER LAF(9,9),LOF(9,9)
 13   DATA XS,XE/1HS,1HE/
      DO 44 I=1,M1
      IF(D(I).EQ.XS) GO TO 14
      GO TO 25
 14   LAD(I)=-LAD(I)
```

```
      YLA(I)=-YLA(I)
25    IF(H(I).EQ.XE)GO TO 35
      GO TO 44
35    LOD(I)=-LOD(I)
      YLO(I)=-YLO(I)
44    WRITE(6,800)LAD(I),YLA(I),LOD(I),YLO(I),D(I),H(I)
800   FORMAT(I6,F10.1,I6,F10.1,'    CHECK:',2A4)
      WRITE(6,801)
801   FORMAT('  CHECK. TYPE Y OR N')
      READ(5,802)CHECK
802   FORMAT(A1)
      RETURN
      END
C
C------------------------------------------------------------------------
C
C                    SUBROUTINE WXCOMP
C
C          PROGRAMMER: LT J. H. DISCENZA, USCG
C
C               THIS SUBROUTINE HANDLES DATA FROM A WEATHER TAPE, AND
C          COMPUTES SET, DRIFT, AND DRIFT ERROR FOR SEVERAL TRACKS AT
C          A TIME.
C               THE WEATHER DATA IS STORED ON TAPE IN "FIELDS".
C          THESE FIELDS  CONTAIN ALL DATA FOR ONE PARAMETER (WIND,
C          CURRENT) FOR THE NORTHERN HEMISPHERE FOR ONE OBSERVATION
C          TIME.   THE REFERENCE SYSTEM FOR THE WEATHER DATA IS A
C          SQUARE GRID, 63 POINTS ON A SIDE, BASED ON A POLAR STEREO-
C          GRAPHIC PROJECTION.   THE POINT 32,32 IS ON THE NORTH POLE.
C          ALL OTHER POINTS MAY BE DETERMINED FROM LATITUDE AND
C          LONGITUDE BY THE FOLLOWING FORMULAE:
C                                                  1/2              O
C          RI=32+ 31.205((1-SIN LAT)/(1+SIN LAT))     X COS(LONG+10  )
C
C                                                  1/2              O
C          RJ=32- 31.205((1-SIN LAT)/(1+SIN LAT))     X SIN(LONG+10  )
C
C               THE PROGRAM BEGINS BY USING THESE FORMULAE TO CONVERT
C          ALL STARTING POSITIONS TO THIS GRID SYSTEM.   THEN IT TESTS
C          THESE COORDINATES FOR EXTREMES AND SELECTS A SET OF WEATHER
C          OBSERVATION POSITIONS LARGE ENOUGH TO PROVIDE SUFFICIENT
C          WEATHER DATA FOR THE PROBLEM.
C               IT THEN SEARCHES THE DATA BANK FOR  THE PROPER TIME
C          INTERVAL AND BEGINS READING IN WEATHER.  THE COMPUTATIONS
C          BEGIN AT THE TIME OF THE EARLIEST APPROPRIATE WEATHER
C          OBSERVATION AND ADVANCES HOUR BY HOUR.  AT EACH TIME (T)
C          THE WEATHER AT THE PREVIOUS OBSERVATION (A3) AND THE WEATHER
C          AT THE NEXT OBSERVATION (A5) ARE USED.  TO FIND THE WEATHER
```

```
C           AT THE EXACT POSITION AT THE EXACT TIME THREE INTERPOLATIONS
C           ARE MADE: (1) INTERPOLATE FOR FOR POSITION IN A3, (2) INTER-
C           POLATE FOR POSITION AT A5, (3) INTERPOLATE FOR TIME BETWEEN
C           A3 AND A5.  AT EACH HOUR, ALL TRACKS ARE ADVANCED ACCORDING
C           TO THE WEATHER CALCULATED FOR THAT TRACK'S POSITION AT THAT
C           HOUR.   WHEN AN INTERMEDIATE DATUM IS REQUIRED, THAT DATUM
C           IS EXTRACTED SEPARATELY FROM THE VARIOUS TRACKS.    WHEN
C           ALL DATUM POINTS REQUIRED HAVE BEEN EXTRACTED THE
C           SUBROUTINE RETURNS TO THE MAIN PROGRAM.
C


      SUBROUTINE WXCOMP
      COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,O,
     1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,
     2DESC(15),FLA(9,18),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,
     3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)
      INTEGER T2(3,9),T3(3),O(9)
      INTEGER A1(3,9),W1(3)
      INTEGER LAF(9,9),LOF(9,9)
      DIMENSION RI(18),RJ(18),DER(18),PI(18),PJ(18),A3(20,20,4),
     1A5(20,20,4),FM(9)
      INTEGER ITIN(9),ITTERM(9),TA(3),T(3),T4(3)
      REAL*8 TITLE(12)
      INTEGER*2 W2(63,63)
      IF(TAP.EQ.0)GO TO 305
C-------------------------------------***DUMMY WX DATA
      DO 307 I=1,63
      DO 307 J=1,63
  307 W2(I,J)=800
C-------------------------------------***END DUMMY DATA
      GO TO 306
  305 CALL TAPSET(2,12,8044,1,3,8040)
  306 READ(4,8001)M12
 8001 FORMAT(I4)
C
C         SET ALL SWITCHES TO ZERO
      IWIN=0
      DO 304 I=1,M4
  304    DER(I)=0.
      DO 201 I=1,M1
  201 ITIN(I)=0
      DO 202 I=1,M2
  202 ITTERM(I)=0
      TERM=0.
      SFW=1.944/16.
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      SFC=.01944/16.                                                    SAR03290
      IF(O(1).EQ.1)WRITE(8,1137)SFW,SFC                                 SAR03300
C                                                                       SAR03310
C           CONVERT LATITUDE AND LONGITUDE OF STARTING POSITIONS        SAR03320
C           TO FLEET NUMERICAL WEATHER FACILITY GRID SYSTEM             SAR03330
      K=0                                                               SAR03340
      DO 161 J=1,M1                                                     SAR03350
  161 CALL FNIO(LAD(J),YLA(J),LOD(J),YLO(J),RI(J),RJ(J),FM(J),K)        SAR03360
      IF(O(1).EQ.1)WRITE(8,1110)(RI(J),RJ(J),J=1,M1)                    SAR03370
C                                                                       SAR03380
      ITS=A1(1,1)                                                       SAR03390
      ITT=A1(2,1)-12                                                    SAR03400
      IF(ITT)226,162,162                                                SAR03410
  226 ITT=ITT+24                                                        SAR03420
      ITS=ITS-1                                                         SAR03430
      IF(O(1).EQ.1)WRITE(8,1119)ITS,ITT                                 SAR03440
C                                                                       SAR03450
C           READ FIELD FOR NEXT TIME INTERVAL                           SAR03460
  162 IF(TAP.EQ.0)READ(12,ERR=2000)TITLE,W2                             SAR03470
      M12=M12+1                                                         SAR03480
      IF(O(1).EQ.1)WRITE(8,1111)                                        SAR03490
      IF(O(1).EQ.1)WRITE(8,1112)TITLE                                   SAR03500
      W1(1)=M12/8                                                       SAR03510
      M13=M12/4                                                         SAR03520
      W1(2)=12*(M13-2*(M13/2))                                          SAR03530
      W1(3)=00                                                          SAR03540
      IF(O(1).EQ.1)WRITE(8,1115)W1                                      SAR03550
      IF(O(5).EQ.1)WRITE(8,1113)                                        SAR03560
      IF(O(5).EQ.1)WRITE(8,1114)(W2(1,J),J=1,4)                         SAR03570
C                                                                       SAR03580
C           TEST INITIALIZE SWITCH 'IWIN'                               SAR03590
      IF(IWIN.EQ.1)GO TO 225                                            SAR03600
C                                                                       SAR03610
C           IF INITIALIZE SWITCH FALSE, COMPARE TIME OF WEATHER         SAR03620
C           OBSERVATION TO TIME OF EARLIEST STARTING POINT              SAR03630
  222 IF(W1(1)-ITS)162,223,224                                          SAR03640
  223 IF(W1(2)-ITT)162,224,224                                          SAR03650
  227 WRITE(6,1105)                                                     SAR03660
      GO TO 2000                                                        SAR03670
C                                                                       SAR03680
C           IF WEATHER IS WITHIN REQUIRED TIME FRAME START DRIFT        SAR03690
C           COMPUTATIONS. SET INITIALIZE SWITCH TO TRUE.                SAR03700
  224 DO 401 I=1,3                                                      SAR03710
  401 T3(I)=W1(I)                                                       SAR03720
      IF(O(1).EQ.1)WRITE(8,1116)W1                                      SAR03730
C                                                                       SAR03740
C           SEARCH STARTING POSITIONS FOR EXTREMES                     4SAR03750
  225 TEMP1=RI(1)                                                       SAR03760
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```
      TEMP2=RI(1)                                                       SAR03770
      TEMP3=RJ(1)                                                       SAR03780
      TEMP4=RJ(1)                                                       SAR03790
      DO 166 I=1,M1                                                     SAR03800
      IF(RI(I).GT.TEMP1)TEMP1=RI(I)                                     SAR03810
      IF(RI(I).LT.TEMP2)TEMP2=RI(I)                                     SAR03820
      IF(RJ(I).GT.TEMP3)TEMP3=RJ(I)                                     SAR03830
  166 IF(RJ(I).LT.TEMP4)TEMP4=RJ(I)                                     SAR03840
C                                                                       SAR03850
C         SELECT MAXIMUM GRID POINTS 3 MESH LENGTHS OUTSIDE.            SAR03860
      IC1=TEMP1+3.                                                      SAR03870
      IC2=TEMP2-3.                                                      SAR03880
      IC3=TEMP3+3.                                                      SAR03890
      IC4=TEMP4-3.                                                      SAR03900
C                                                                       SAR03910
C     DETERMINE SIZE OF WEATHER MATRIX TO BE SELECTED                   SAR03920
      N8=IC1-IC2                                                        SAR03930
      M8=IC3-IC4                                                        SAR03940
      IF(O(2).EQ.1)WRITE(8,1118)IC3,M8,IC2,IC1,N8,IC4                   SAR03950
C                 TEST FOR MINIMAX                                      SAR03960
      IF(M4.EQ.M1)GO TO 263                                             SAR03970
C                                                                       SAR03980
C                                                                       SAR03990
C     IF MINIMAX, EXPAND SET OF STARTING POSITIONS TO DOUBLE            SAR04000
C     ORIGINAL SIZE TO ACCOMODATE TWO TRACKS FOR EACH STARTING          SAR04010
C     POINT.                                                            SAR04020
      DO 209 J=1,M1                                                     SAR04030
      K=M1+J                                                            SAR04040
      RI(K)=RI(J)                                                       SAR04050
  209 RJ(K)=RJ(J)                                                       SAR04060
      DO 210 I=1,M1                                                     SAR04070
      K=M1+I                                                            SAR04080
      J=2*I                                                             SAR04090
      RI(J)=RI(K)                                                       SAR04100
      RJ(J)=RJ(K)                                                       SAR04110
      RI(J-1)=RI(K)                                                     SAR04120
  210 RJ(J-1)=RJ(K)                                                     SAR04130
      IF(O(4).EQ.1)WRITE(8,1133)(RI(L),RJ(L),L=1,M4)                    SAR04140
  263 CONTINUE                                                          SAR04150
C                                                                       SAR04160
C     SELECT APPROPRIATE WEATHER AND STORE IN A3                        SAR04170
      DO 169 M=1,4                                                      SAR04180
      IF(IWIN.EQ.0.AND.M.EQ.1)GO TO 168                                 SAR04190
      IF(TAP.EQ.0)READ(12,ERR=2000)TITLE,W2                             SAR04200
      M12=M12+1                                                         SAR04210
      W1(1)=M12/8                                                       SAR04220
      M13=M12/4                                                         SAR04230
      W1(2)=12*(M13-2*(M13/2))                                          SAR04240
```

```
      IF(O(1).EQ.1)WRITE(8,1115)W1                                      SAR04250
      IF(O(1).EQ.1)WRITE(8,1112)TITLE                                   SAR04260
168   CONTINUE                                                          SAR04270
      DO 169 J=1,M8                                                     SAR04280
      DO 169 I=1,N8                                                     SAR04290
      K=I+IC2                                                           SAR04300
      L=J+IC4                                                           SAR04310
      KX=W2(K,L)                                                        SAR04320
  169 A3(I,J,M)=KX                                                      SAR04330
      IWIN=1                                                            SAR04340
      IF(O(4).EQ.1)WRITE(8,1138)((K1,K2,(A3(K1,K2,K3),K3=1,4),K2=1,M8),KSAR04350
     11=1,N8)                                                           SAR04360
      GO TO 181                                                         SAR04370
C                                                                       SAR04380
C          AFTER HAVING READ IN TWO TIME INTERVALS OF WEATHER, THE      SAR04390
C          PROGRAM PERFORMS THE DRIFT CALCULATIONS UP TO THE TIMW OF    SAR04400
C          THE SECOND INTERVAL, AND THEN RETURNS TO THIS POINT. THE     SAR04410
C          DATA FROM TA IS TRANSFERRED TO T3, AND THE DATA FROM A5 TO   SAR04420
C          A3 IN ORDER TO CONTINUE INTO THE NEXT TIME INTERVAL.         SAR04430
  165 DO 211 J=1,M8                                                     SAR04440
      DO 211 I=1,N8                                                     SAR04450
      DO 211 JJ=1,4                                                     SAR04460
  211 A3(I,J,JJ)=A5(I,J,JJ)                                             SAR04470
      DO 212 I=1,3                                                      SAR04480
  212 T3(I)=TA(I)                                                       SAR04490
C                                                                       SAR04500
C          READ WEATHER FIELD FOR NEXT OBSERVATION                      SAR04510
  181 CONTINUE                                                          SAR04520
      DO 163 M=1,4                                                      SAR04530
      IF(TAP.EQ.0)READ(12,ERR=2000)TITLE,W2                             SAR04540
      M12=M12+1                                                         SAR04550
      W1(1)=M12/8                                                       SAR04560
      M13=M12/4                                                         SAR04570
      W1(2)=12*(M13-2*(M13/2))                                          SAR04580
      IF(O(1).EQ.1)WRITE(8,1115)W1                                      SAR04590
      IF(O(1).EQ.1)WRITE(8,1112)TITLE                                   SAR04600
C                                                                       SAR04610
C          SELECT APPPOPRIATE WEATHER AND STORE IN A5                   SAR04620
      DO 163 J=1,M8                                                     SAR04630
      DO 163 I=1,N8                                                     SAR04640
      K=I+IC2                                                           SAR04650
      L=J+IC4                                                           SAR04660
      KX=W2(K,L)                                                        SAR04670
  163 A5(I,J,M)=KX                                                      SAR04680
      IF(O(4).EQ.1)WRITE(8,1138)((K1,K2,(A5(K1,K2,K3),K3=1,4),K2=1,M8),KSAR04690
     11=1,N8)                                                           SAR04700
      DO 172 I=1,3                                                      SAR04710
      TA(I)=W1(I)                                                       SAR04720
```

```
  172 T(I)=T3(I)                                                          SAR04730
      IF(O(3).EQ.1)WRITE(8,1117)TA,T                                      SAR04740
C                                                                         SAR04750
  171 CONTINUE                                                            SAR04760
      DO 170 J=1,M1                                                       SAR04770
      IF(O(2).EQ.1)WRITE(8,1101)                                          SAR04780
      IF(O(2).EQ.1)WRITE(8,1102)J                                         SAR04790
C                                                                         SAR04800
C     TEST STARTING POINT INITIALIZE SWITCH TO SEE IF THE                6SAR04810
C     TRACK(S) FOR EACH STARTING POINT HAVE BEGUN DRIFTING.               SAR04820
      IF(ITIN(J).EQ.1)GO TO 175                                           SAR04830
C                                                                         SAR04840
C     IF NOT BEGUN, TEST STARTING DATES AND TIMES.                  7,8,9SAR04850
      IF(O(2).EQ.1)WRITE(8,1103)T(1),A1(1,J)                              SAR04860
      IF(T(1)-A1(1,J))170,173,174                                         SAR04870
  173 IF(O(2).EQ.1)WRITE(8,1104)T(2),A1(2,J)                              SAR04880
      IF(T(2)-A1(2,J))170,176,174                                         SAR04890
  176 IF(O(2).EQ.1)WRITE(8,1106)                                          SAR04900
      IF(T(3)-A1(3,J))177,178,179                                         SAR04910
C                                                                         SAR04920
C     SET VALUE OF R, THE PORTION OF THE FIRST HOUR DRIFTING.    10,11,12SAR04930
  177 R=FLOAT(A1(3,J)-T(3))/60.                                           SAR04940
      GO TO 180                                                           SAR04950
  178 R=1.                                                                SAR04960
      GO TO 180                                                           SAR04970
  179 WRITE(6,1107)                                                       SAR04980
      R=1.+FLOAT(T(3)-A1(3,J))/60.                                        SAR04990
      GO TO 180                                                           SAR05000
  175 IF(O(2).EQ.1)WRITE(8,1108)                                          SAR05010
C                                                                         SAR05020
C     TEST DATUM TIME TERMINATION SWITCH. IF TRUE, TEST NEXT              SAR05030
C     DATUM TIME.                                                 13 - 16SAR05040
      DO 181 II=1,M2                                                      SAR05050
      IF(ITTERM(II).EQ.0)GO TO 189                                        SAR05060
  181 CONTINUE                                                            SAR05070
      WRITE(6,1105)                                                       SAR05080
  189 K=II                                                                SAR05090
      IF(O(2).EQ.1)WRITE(8,1109)K                                         SAR05100
      IF(O(2).EQ.1)WRITE(8,1103)T(1),T2(1,K)                              SAR05110
      IF(T(1)-T2(1,K))182,183,174                                         SAR05120
  183 IF(O(2).EQ.1)WRITE(8,1104)T(2),T2(2,K)                              SAR05130
      IF(T(2)-T2(2,K))182,184,174                                         SAR05140
  174 WRITE(6,1105)                                                       SAR05150
      GO TO 2000                                                          SAR05160
C                                                                         SAR05170
C          SET VALUE OF R, THE PORTION OF AN HOUR THIS PARTICULAR       17SAR05180
C          TRACK IS TO DRIFT.                                             SAR05190
  182 R=1.                                                                SAR05200
```

```
      GO TO 190                                                         SAR05210
  184 IF(O(2).EQ.1)WRITE(8,1106)                                        SAR05220
      IF(T(3)-T2(3,K))185,186,187                                       SAR05230
C                                                                       SAR05240
C          SET VALUE OF S, THE PORTION OF AN HOUR DRIFTED TOWARD 18,19,20SAR05250
C          A PARTICULAR DATUM TIME.                                     SAR05260
  185 S=FLOAT(T2(3,K)-T(3))/60.                                         SAR05270
      GO TO 188                                                         SAR05280
  186 S=0.                                                              SAR05290
      GO TO 188                                                         SAR05300
  187 WRITE(6,1107)                                                     SAR05310
      S=FLOAT(T2(3,K)-T(3))/60.                                         SAR05320
C                                                                       SAR05330
C          SET DATUM TIME TERMINATION SWITCH TRUE.                    23SAR05340
  188 ITTERM(K)=1                                                       SAR05350
      IF(K.NE.M2.OR.J.NE.M1)GO TO 180                                   SAR05360
      TERM=1.                                                           SAR05370
C                                                                       SAR05380
C          INTERPOLATE WIND AND CURRENT FOR THIS POSITION.            24SAR05390
  180 IM=M4/M1                                                          SAR05400
      L =J*IM-IM+1                                                      SAR05410
  226 IT1= IFIX(RI(L))-IC2                                              SAR05420
      JT1= IFIX(RJ(L))-IC4                                              SAR05430
      QI=RI(L)-FLOAT(IT1+IC2)                                           SAR05440
      QJ=RJ(L)-FLOAT(JT1+IC4)                                           SAR05450
      IF(O(1).EQ.1)WRITE(8,1140)QI,QJ                                   SAR05460
      IT2=IT1+1                                                         SAR05470
      JT2=JT1+1                                                         SAR05480
      WU=A3(IT1,JT1,3)+QJ*(A3(IT1,JT2,3)-A3(IT1,JT1,3))                 SAR05490
      WV=A3(IT1,JT1,4)+QJ*(A3(IT1,JT2,4)-A3(IT1,JT1,4))                 SAR05500
      XU=A3(IT2,JT1,3)+QJ*(A3(IT2,JT2,3)-A3(IT2,JT1,3))                 SAR05510
      XV=A3(IT2,JT1,4)+QJ*(A3(IT2,JT2,4)-A3(IT2,JT1,4))                 SAR05520
      WI=WU+QI*(XU-WU)                                                  SAR05530
      WJ=WV+QI*(XV-WV)                                                  SAR05540
      CU=A3(IT1,JT1,1)+QJ*(A3(IT1,JT2,1)-A3(IT1,JT1,1))                 SAR05550
      CV=A3(IT1,JT1,2)+QJ*(A3(IT1,JT2,2)-A3(IT1,JT1,2))                 SAR05560
      DU=A3(IT2,JT1,1)+QJ*(A3(IT2,JT2,1)-A3(IT2,JT1,1))                 SAR05570
      DV=A3(IT2,JT1,2)+QJ*(A3(IT2,JT2,2)-A3(IT2,JT1,2))                 SAR05580
      CI=CU+QI*(DU-CU)                                                  SAR05590
      CJ=CV+QI*(DV-CV)                                                  SAR05600
      WU=A5(IT1,JT1,3)+QJ*(A5(IT1,JT2,3)-A5(IT1,JT1,3))                 SAR05610
      WV=A5(IT1,JT1,4)+QJ*(A5(IT1,JT2,4)-A5(IT1,JT1,4))                 SAR05620
      XU=A5(IT2,JT1,3)+QJ*(A5(IT2,JT2,3)-A5(IT2,JT1,3))                 SAR05630
      XV=A5(IT2,JT1,4)+QJ*(A5(IT2,JT2,4)-A5(IT2,JT1,4))                 SAR05640
      WU=WU+QI*(XU-WU)                                                  SAR05650
      WV=WV+QI*(XV-WV)                                                  SAR05660
      CU=A5(IT1,JT1,1)+QJ*(A5(IT1,JT2,1)-A5(IT1,JT1,1))                 SAR05670
      CV=A5(IT1,JT1,2)+QJ*(A5(IT1,JT2,2)-A5(IT1,JT1,2))                 SAR05680
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      DU=A5(IT2,JT1,1)+OJ*(A5(IT2,JT2,1)-A5(IT2,JT1,1))                SAR05690
      DV=A5(IT2,JT1,2)+OJ*(A5(IT2,JT2,2)-A5(IT2,JT1,2))                SAR05700
      CU=CU+OI*(DU-CU)                                                  SAR05710
      CV=CV+OI*(DV-CV)                                                  SAR05720
C                                                                       SAR05730
C           INTERPOLATE WEATHER DATA AS TO TIME                         SAR05740
      HRR=FLOAT(T(2)-T3(2))/12.                                         SAR05750
      IF(O(4).EQ.1)WRITE(8,1139)WU,WV,CU,CV,WI,WJ,CI,CJ                 SAR05760
      IF(T(1).EQ.T3(1))GO TO 204                                        SAR05770
      HRR=HRR+2.                                                        SAR05780
  204 WU=(WI+HRR*(WU-WI))*SFW                                           SAR05790
      WV=(WJ+HRR*(WV-WJ))*SFW                                           SAR05800
      CU=(CI+HRR*(CU-CI))*SFC                                           SAR05810
      CV=(CJ+HRR*(CV-CJ))*SFC                                           SAR05820
      IF(O(4).EQ.1)WRITE(8,1139)WU,WV,CU,CV                             SAR05830
C                                                                       SAR05840
C           SURVIVOR CRAFT LEEWAY FACTORS.                              SAR05850
      WWV=ABS(WV)                                                       SAR05860
      IF(WWV.LT.1.)GO TO 207                                            SAR05870
      ANG=ATAN(WU/WV)                                                   SAR05880
      ANG=ANG/P                                                         SAR05890
      GO TO 208                                                         SAR05900
  207 ANG=0.                                                            SAR05910
  208 WVV=SQRT(WU*WU+WV*WV)                                             SAR05920
      WWVV=SQRT(WWV)                                                    SAR05930
      IF(WV.LT.0)ANG=ANG-180.                                           SAR05940
      NN=J*IN-IN+1                                                      SAR05950
      IF(L.NE.NN)GO TO 205                                              SAR05960
C-----------------WIND DRIFT FACTORS--------                            SAR05970
      WIND(1,J,K)=WVV                                                   SAR05980
      WIND(2,J,K)=ANG+180.                                              SAR05990
      WVV=WWVV*(CV1+CV3*WWVV)                                           SAR06000
      ANG=ANG+CD1                                                       SAR06010
C-------------------------------------------                            SAR06020
      GO TO 206                                                         SAR06030
C-------------------------------------------                            SAR06040
  205 WVV=WWVV*(CV2+CV4*WWVV)                                           SAR06050
      WIND(1,J,K)=(WIND(1,J,K)+WVV)/2.                                  SAR06060
      WIND(2,J,K)=(WIND(2,J,K)+ANG+180.)/2.                             SAR06070
      ANG=ANG+CD2                                                       SAR06080
C-------------------------------------------                            SAR06090
  206 WV=WVV*SIN(ANG)                                                   SAR06100
      WU=WVV*COS(ANG)                                                   SAR06110
      IF(ITTERM(K).NE.1)GO TO 220                                       SAR06120
C                                                                       SAR06130
C           CALCULATE U AND V COMPONENTS IN MILES, FOR S HOURS.         SAR06140
      X=S*(WU+CU)                                                       SAR06150
      Y=S*(WV+CV)                                                       SAR06160
```

```
C                                                                       SAR06170
C         INCREMENT DRIFT ERROR                                         SAR06180
      DD(K,L)=DER(L)+SQRT(X*X+Y*Y)/8.                                   SAR06190
C                                                                       SAR06200
C     ADVANCE POSITIONS TO DATUM TIME IN FNWF COORDINATE SYSTEM         SAR06210
      PI(L)=RI(L)+X/FM(J)                                               SAR06220
      PJ(L)=RJ(L)+Y/FM(J)                                               SAR06230
      IF(O(1).EQ.1)WRITE(8,1134)L,FM(J),X,Y,PI(L),PJ(L)                 SAR06240
C                                                                       SAR06250
C         CONVERT FROM GRID SYSTEM TO GEOGRAPHIC COORDINATES.           SAR06260
      MNO=1                                                             SAR06270
      CALL FNIO(LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L),PI(L),PJ(L),FM(J),MNSAR06280
     1O)                                                                SAR06290
      IF(O(1).EQ.1)WRITE(8,1136)XLAT,XLON,LAF(K,L),FLA(K,L),LOF(K,L),FLOSAR06300
     1(K,L)                                                             SAR06310
      WRITE(6,1120)K,L,LAF(K,L),FLA(K,L),LOF(K,L),FLO(K,L)              SAR06320
C                                                                       SAR06330
C         TEST TERMINATE SWITCH. IF FALSE, ADVANCE ALL TRACKS           SAR06340
C         ONE HOUR                                                      SAR06350
      NN=J*IM                                                           SAR06360
      IF(J.NE.M1.AND.L.EQ.NN)ITTERM(K)=0                                SAR06370
      IF(TERM.NE.1)GO TO 220                                            SAR06380
      IF(M4.EQ.M1)GO TO 230                                             SAR06390
      IF(L.EQ.NN)GO TO 230                                              SAR06400
      GO TO 240                                                         SAR06410
  220 X=R*(WU+CU)                                                       SAR06420
      Y=R*(WV+CV)                                                       SAR06430
C                                                                       SAR06440
C         INCREMENT DRIFT ERROR                                         SAR06450
      DER(L)=DER(L)+SQRT(X*X+Y*Y)/8.                                    SAR06460
C                                                                       SAR06470
C         ADVANCE POSITIONS R HOURS IN FNWF COORDINATE SYSTEM.          SAR06480
      RI(L)=RI(L)+X/FM(J)                                               SAR06490
      RJ(L)=RJ(L)+Y/FM(J)                                               SAR06500
      IF(O(1).EQ.1)WRITE(8,1135)L,FM(J),X,Y,RI(L),RJ(L)                 SAR06510
      IF(M4.EQ.M1)GO TO 250                                             SAR06520
      NN=J*IM                                                           SAR06530
      IF(L.EQ.NN)GO TO  250                                             SAR06540
  240 L=J*IM                                                            SAR06550
      GO TO 228                                                         SAR06560
  250 ITIN(J)=1                                                         SAR06570
  170 CONTINUE                                                          SAR06580
C                                                                       SAR06590
C         INCREMENT TIME ONE HOUR.                                      SAR06600
      T(2)=T(2)+1                                                       SAR06610
      IF(T(2).LT.24)GO TO 251                                           SAR06620
      T(2)=T(2)-24                                                      SAR06630
      T(1)=T(1)+1                                                       SAR06640
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251  IF(T(2).EQ.TA(2))GO TO 165                                                    SAR06650
     GO TO 171                                                                     SAR06660
 230 CONTINUE                                                                      SAR06670
2000 CONTINUE                                                                      SAR06680
1101 FORMAT(' BEGIN LOOP')                                                         SAR06690
1102 FORMAT('    STARTING POINT',I3)                                               SAR06700
1103 FORMAT(7X,'TEST DATE'7X'WX DATE:'I5'START DATE:'I5)                           SAR06710
1104 FORMAT(7X,'TEST HOUR: WX HOUR-'I6'    START HOUR-'I6)                         SAR06720
1105 FORMAT(' ****ERROR    **** PROGRAM TERMINATING')                              SAR06730
1106 FORMAT(7X,'TEST MINUTES')                                                     SAR06740
1107 FORMAT(' **WARNING** RESULTS MAY BE ERRONEOUS')                               SAR06750
1108 FORMAT(7X,'TRACKS HAVE STARTED. CHECKING DATUM TIMES.')                       SAR06760
1109 FORMAT(' SEARCH',I2,' NEXT:')                                                 SAR06770
1110 FORMAT(' RI:',F10.5,'  RJ:',F10.5)                                            SAR06780
1262     FORMAT(20I4)                                                              SAR06790
1263  FORMAT(15A4)                                                                 SAR06800
1264 FORMAT(6X'O'11X'A'11X'TLCT'8X'S'11X'C'/5F12.5)                                SAR06810
1111  FORMAT('OWEATHER DATA FIELD TITLES:'//' HRS FCTS  HOUR     DATE              SAR06820
    1U/V   PARAMETER')                                                             SAR06830
1112 FORMAT(12A8)                                                                  SAR06840
1113 FORMAT('OSAMPLE FROM WEATHER FIELD:')                                         SAR06850
1114 FORMAT(4I20)                                                                  SAR06860
1115 FORMAT(' WEATHER READ FOR DATE-TIME:'3I6)                                     SAR06870
1116 FORMAT(12X'T3 DATE-TIME SET:'3I6)                                             SAR06880
1117 FORMAT(15X'TA DATE-TIME:'3I6//20X'T DATE-TIME SET:'3I6)                       SAR06890
1118 FORMAT(' MAXIMUM GRID POINTS:'I10/I21/I10,I12,I10/I22)                        SAR06900
1119 FORMAT(' ACCEPT ANY WX OBS AFTER'2I6)                                         SAR06910
1120 FORMAT(' SEARCH'I2', TRACK'I3', DATUM:',2(I6,F6.2))                           SAR06920
1133 FORMAT('OEXPAND STARTING POINTS TO ACCOMMODATE MINIMAX'//                     SAR06930
   114X,'I',19X,'J'//(2F20.5))                                                     SAR06940
1134 FORMAT(' SEARCH TRACK'I2,F20.10,2F10.5,2F20.10)                               SAR06950
1135 FORMAT(9X,'TRACK'I2,F20.10,2F10.5,2F20.10)                                    SAR06960
1136 FORMAT(' SEARCH GEOGR:',2F10.6,2(I7,F7.2))                                    SAR06970
1137 FORMAT(' SCALE FACTORS=        WIND:',F20.10,'   CURR:'F20.10)                SAR06980
1138 FORMAT('      WEATHER MATRIX RETAINED:'//(2I5,4F30.1))                        SAR06990
1139 FORMAT(' WIND, U,V:',2F15.5,'    CURRENT, U,V:',2F15.5)                       SAR07000
1140 FORMAT(10X,'QI:'F15.5,'       QJ:'F15.5)                                      SAR07010
     RETURN                                                                        SAR07020
     END                                                                           SAR07030
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      SUBROUTINE DATUM                                                  SAR07040
C          PROGRAMMER: LT J. H. DISCENZA, USCG                          SAR07050
      COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,O,          SAR07060
     1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MCN(9),IX1,IX2,TAP,                SAR07070
     2DESC(15),FLA(9,18),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,    SAR07080
     3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)                SAR07090
      INTEGER T2(3,9),T3(3),O(9)                                        SAR07100
      INTEGER A1(3,9)                                                   SAR07110
      INTEGER LAF(9,9),LOF(9,9)                                         SAR07120
      DATA XN,S,E,W/1HN,1HS,1HE,1HW/                                    SAR07130
      IF(O(1).EQ.1)WRITE(8,1061)                                        SAR07140
 1061 FORMAT(' ENTERING DATUM')                                         SAR07150
      IF(M4.EQ.M1)GO TO 302                                             SAR07160
      IF(O(1).EQ.1)WRITE(8,1062)                                        SAR07170
      DO 301 I=1,M2                                                     SAR07180
      DO 301 K=1,M1                                                     SAR07190
      J=2*K                                                             SAR07200
      ALA=(FLOAT(LAF(I,J-1)+LAF(I,J))+(FLA(I,J-1)+FLA(I,J))/60.)/2.     SAR07210
      ALO=(FLOAT(LOF(I,J-1)+LOF(I,J))+(FLO(I,J-1)+FLO(I,J))/60.)/2.     SAR07220
      ADD=(DD(I,J-1)-DD(I,J))/120.                                      SAR07230
      DLA=(FLOAT(LAF(I,J-1)-LAF(I,J))+(FLA(I,J-1)-FLA(I,J))/60.)        SAR07240
      DLO=COS(ALA*P)*(FLOAT(LOF(I,J-1)-LOF(I,J))+(FLO(I,J-1)-FLO(I,J))/6SAR07250
     10.)                                                               SAR07260
      DXX=SQRT(DLA*DLA+DLO*DLO)                                         SAR07270
      FLA(I,K)=ALA*60.                                                  SAR07280
      LAF(I,K)=FLA(I,K)/60.                                             SAR07290
      FLA(I,K)=FLA(I,K)-FLOAT(LAF(I,K))*60.                             SAR07300
      FLO(I,K)=ALO*60.                                                  SAR07310
      LOF(I,K)=FLO(I,K)/60.                                             SAR07320
      FLO(I,K)=FLO(I,K)-FLOAT(LOF(I,K))*60.                             SAR07330
      IF(O(1).EQ.1)WRITE(8,1063)I,J,K,ALA,ALO,ADD,DLO,DLA,LAF(I,K),FLA(ISAR07340
     1,K),LOF(I,K),FLO(I,K)                                             SAR07350
  301 DD(I,K)=(DD(I,J)+DD(I,J-1)+DXX)/2.                                SAR07360
  302 CONTINUE                                                          SAR07370
      DO 151 I=1,M2                                                     SAR07380
      DO 151 J=1,M1                                                     SAR07390
      WIND(2,J,I)=WIND(2,J,I)+FLOAT(LOF(I,J))+FLO(I,J)/60.-10.          SAR07400
      IF(LAF(I,J))52,55,53                                              SAR07410
   55 IF(FLA(I,J))52,53,53                                              SAR07420
   53 DE(I,J)=XN                                                        SAR07430
      GO TO 54                                                          SAR07440
   52 DE(I,J)=S                                                         SAR07450
      LAF(I,J)=-LAF(I,J)                                                SAR07460
      FLA(I,J)=-FLA(I,J)                                                SAR07470
   54 IF(LOF(I,J))56,57,58                                              SAR07480
   57 IF(FLO(I,J))56,58,58                                              SAR07490
   58 HE(I,J)=W                                                         SAR07500
      GO TO 151                                                         SAR07510
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56    HE(I,J)=E
      LOF(I,J)=-LCF(I,J)
      FLO(I,J)=-FLO(I,J)
 2    IF(LOF(I,J).LT.360)GO TO 151
      LOF(I,J)=LOF(I,J)-360
      GO TO 2
151   CONTINUE
1062  FORMAT(2X,'SEARCH',5X,'TRACK',5X,'START',6X,'ALA'7X,'ALO',7X,'ADD'
     17X,'DLA',7X,'DLO',7X,'LAF',7X,'FLA',7X,'LOF',7X,'FLO')
1063  FORMAT(I5,2I10,F13.3,4F10.3,I10,F10.3,I10,F10.3)
      RETURN
      END
C-------------------------------------------------------------------------
C
C                     SUBROUTINE RADII
C                     PROGRAMMER: LT J.H. DISCENZA,USCG
C
C               THIS SUBROUTINE COMPUTES THE PROPER SERACH RADIUS FOR
C           EACH DATUM POINT IN EACH SEARCH. IF THERE IS TO BE "NO"
C           SEARCH AT A PARTICULAR DATUM TIME, SEARCH RADII FOR THAT
C           TIME ARE SET AT ZERO.
C
C           ENTERING ARGUMENTS:
C
C                 LAD,YLA,LOD,YLO: LATITUDES AND LONGITUDES OF STARTING
C                     POSITIONS
C                 LAK,ALK,LOK,OLK: LATITUDE AND LONGITUDE OF LAST KNOWN
C                     POSITION
C                 IX1: DRIFT RATE AS PERCENT OF WIND
C                 IX2: DRIFT DIVERGENCE IN TENS OF DEGREES
C                 X1,X2: COEFFICIENTS OF EQUATION FOR DETERMINING
C                    DISTRESS CRAFT POSITION ERROR
C                 Y: SEARCH CRAFT POSITION ERROR
C                 KJ: SEARCH NUMBER
C           INTERMEDIATE ARGUMENTS GENERATED:
C                 COSLAT: COSINE OF LATITUDE, LAST KNOWN POSITION
C                 X: DISTRESS CRAFT POSITION ERROR
C                 C: TOTAL PROBABLE ERROR
C                 SF: SAFETY FACTOR (BASED ON SEARCH NUMBER)
C                 DX: DISTANCE FROM LAST KNOWN POSITION
C           OUTPUTS:
C                 RADIUS: SEARCH RADIUS (RADIUS=0. INDICATES NO
C                    CALCULATION OF SEARCH AREA DESIRED FOR THAT TIME.)
C
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      SUBROUTINE RADII                                                  SAR07960
      COMMON LAD(9),YLA(9),D(9),LOD(9),YLO(9),H(9),M1,CHECK,O,          SAR07970
     1DE(9,9),HE(9,9),T2,T3,A1,TZ(9),MON(9),IX1,IX2,TAP,                SAR07980
     2DESC(15),FLA(9,18),FLO(9,18),LAF,LOF,M2,M4,M6,CV1,CV2,CV3,CV4,    SAR07990
     3CD1,CD2,P,DD(9,18),RADIUS(9,9),C(9,18),WIND(2,9,9)                SAR08000
      INTEGER T2(3,9),T3(3),O(9)                                        SAR08010
      INTEGER A1(3,9)                                                   SAR08020
      INTEGER LAF(9,9),LOF(9,9),KR(9)                                   SAR08030
      DIMENSION SF(9)                                                   SAR08040
C         ENTER LAST  KNOWN POSITION                                    SAR08050
      WRITE(6,3001)                                                     SAR08060
 3001 FORMAT(' ENTER LAST KNOWN POSITION. EX: 3522.0N,07653.0W')        SAR08070
      READ(5,3002)LAK,ALK,LCK,CLK                                       SAR08080
 3002 FORMAT(I2,F4.0,2X,I3,F4.0)                                        SAR08090
C                                                                    102SAR08100
      COSLAT=COS((FLOAT(LAK)+ALK/60.)*P)                                SAR08110
C                                                                    103SAR08120
      WRITE(6,3003)DESC                                                 SAR08130
 3003 FORMAT(' IS ',15A4)                                               SAR08140
      WRITE(6,3004)                                                     SAR08150
 3004 FORMAT(' A (1)BOAT, (2)SHIP, OR (3)AIRCRAFT?(ENTER 1,2,OR3)'     )SAR08160
      READ(5,3005)LL                                                    SAR08170
 3005 FORMAT(I1)                                                        SAR08180
      IF(LL-2)602,603,604                                               SAR08190
C         SMALL BOATS                                                104SAR08200
  602 X1=15.                                                            SAR08210
      X2=.15                                                            SAR08220
      GO TO 605                                                         SAR08230
C         SHIPS                                                      105SAR08240
  603 X1=5.                                                             SAR08250
      X2=.05                                                            SAR08260
      GO TO 605                                                         SAR08270
C         AIRCRAFT                                                   106SAR08280
  604 X1=10.                                                            SAR08290
      X2=.1                                                             SAR08300
C                                                                    107SAR08310
  605 WRITE(6,3006)                                                     SAR08320
 3006 FORMAT(' ENTER SEARCH UNIT FIX ERROR, Y. EX: 5.0')                SAR08330
      READ(5,3007)Y                                                     SAR08340
 3007 FORMAT(F20.0)                                                     SAR08350
      YSQ=Y*Y                                                           SAR08360
C                                                                    108SAR08370
      WRITE(6,3008)                                                     SAR08380
C                                                                    109SAR08390
 3008 FORMAT(' INDICATED DISTRESS CRAFT POSITION ERROR,X:')             SAR08400
      WRITE(6,3009)X1,X2                                                SAR08410
 3009 FORMAT(' X=',F6.2,'(1) +',F6.2,'(2) TIMES DIST. FROM LAST KNOWN POSAR08420
     1SITION.')                                                         SAR08430
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  610 WRITE(6,3010)                                                          SAR08440
 3010 FORMAT(' ANY CORRECTIONS? (TYPE 0,1,2, OR 12)')                        SAR08450
      READ(5,3011)L1,L2                                                      SAR08460
 3011 FORMAT(2I1)                                                            SAR08470
      IF(L1-1)606,607,608                                                    SAR08480
  607 WRITE(6,3012)L1                                                        SAR08490
 3012 FORMAT(' ENTER PARAMETER(',I1,'):')                                    SAR08500
      READ(5,3007)X1                                                         SAR08510
      IF(L2-2)606,608,609                                                    SAR08520
  608 WRITE(6,3012)L2                                                        SAR08530
      READ(5,3007)X2                                                         SAR08540
      GO TO 606                                                              SAR08550
  609 WRITE(6,3013)L2                                                        SAR08560
 3013 FORMAT(' INCORRECT RESPONSE:',I1,' -NO PARAMETER GREATER THAN 2.')SAR08570
      GO TO 610                                                              SAR08580
C                                                                         112SAR08590
  606 DO 611 J=1,M1                                                          SAR08600
      DXN=FLOAT(LAD(J)-LAK)*60.+YLA(J)-ALK                                   SAR08610
      DXW=(FLOAT(LOD(J)-LOK)*60.+YLO(J)-OLK)/COSLAT                          SAR08620
      DX=SQRT(DXN*DXN+DXW*DXW)                                               SAR08630
      X=X1+X2*DX                                                             SAR08640
      XSQ=X*X                                                                SAR08650
      DO 611 I=1,M2                                                          SAR08660
  611 C(I,J)=SQRT(XSQ+YSQ+DD(I,J)*DD(I,J))                                   SAR08670
      WRITE(6,3014)                                                          SAR08680
 3014 FORMAT(' IS EACH DATUM TIME A DIFFERENT SEARCH (1,2,3,ETC.)?')         SAR08690
      READ(5,3017)RESP                                                       SAR08700
 3017 FORMAT(1A1)                                                            SAR08710
      DATA WRONG/1HN/                                                        SAR08720
      IF(RESP.EQ.WRONG)GO TO 612                                             SAR08730
      GO TO 613                                                              SAR08740
  612 WRITE(6,3015)                                                          SAR08750
 3015 FORMAT(' ENTER SEARCH NUMBER CORRESPONDING TO DATUM TIME:')            SAR08760
      DO 614 I=1,M2                                                          SAR08770
      WRITE(6,3016)(T2(J,I),J=1,3)                                           SAR08780
 3016 FORMAT(3I2,' SEARCH:')                                                 SAR08790
  614 READ(5,3005)KR(I)                                                      SAR08800
      GO TO 615                                                              SAR08810
  613 DO 616 I=1,M2                                                          SAR08820
  616 KR(I)=I                                                                SAR08830
  615 DO 617 J=1,M2                                                          SAR08840
      IF(KR(J).EQ.0)GO TO 618                                                SAR08850
C                                                                         131SAR08860
      IF(KR(J).GE.5)GO TO 625                                                SAR08870
C                                                                         132SAR08880
      KK=KR(J)                                                               SAR08890
      GO TO(621,622,623,624),KK                                              SAR08900
C                                                                         133SAR08910
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621  SF(J)=1.1                                          SAR08920
     GO TO 617                                          SAR08930
622  SF(J)=1.6                                          SAR08940
     GO TO 617                                          SAR08950
623  SF(J)=2.0                                          SAR08960
     GO TO 617                                          SAR08970
624  SF(J)=2.3                                          SAR08980
     GO TO 617                                          SAR08990
625  SF(J)=2.5                                          SAR09000
     GO TO 617                                          SAR09010
618  SF(J)=0.                                           SAR09020
617  CONTINUE                                           SAR09030
     DO 619 I=1,M2                                      SAR09040
     DO 619 J=1,M1                                      SAR09050
619  RADIUS(I,J)=SF(I)*C(I,J)                           SAR09060
     RETURN                                             SAR09070
     END                                                SAR09080


     SUBROUTINE FNIO(LAT,TLA,LOT,TLO,SI,SJ,FM,K)        SAR09090
     IF(K.GT.0)GO TO 1                                  SAR09100
     TLAT=(FLOAT(LAT)+TLA/60.)/57.29578                 SAR09110
     TLOT=(FLOAT(LOT)+TLO/60.+10.)/57.29578             SAR09120
     Q=SIN(TLAT)                                        SAR09130
     A=31.205*SQRT((1-Q)/(1+Q))                         SAR09140
     S=SIN(TLOT)                                        SAR09150
     CC=COS(TLOT)                                       SAR09160
     SI=32.+A*CC                                        SAR09170
     SJ=32.-A*S                                         SAR09180
     GO TO 3                                            SAR09190
1    XX=SI-32.                                          SAR09200
     YY=32.-SJ                                          SAR09210
     IF(ABS(XX).GE.0.00005)GO TO 4                      SAR09220
     XLON=80.                                           SAR09230
     IF(YY.LT.0.)XLON=-100.                             SAR09240
     GO TO 5                                            SAR09250
4    TN=YY/XX                                           SAR09260
     XLON=ATAN(TN)*57.29578-10.                         SAR09270
5    IF(XX.LT.0.)XLON=XLON+180.                         SAR09280
     RSQ=XX*XX+YY*YY                                    SAR09290
     RSE=973.752                                        SAR09300
     Q =(RSE-RSQ)/(RSE+RSQ)                             SAR09310
     XLAT=ARSIN(Q)*57.29578                             SAR09320
     LAT=XLAT                                           SAR09330
     LOT=XLON                                           SAR09340
     TLA=60.*(XLAT-FLOAT(LAT))                          SAR09350
```

```
      TLO=60.*(XLON-FLOAT(LOT))                                         SAR09360
    3 FM=388.8556/(1.+O)                                                SAR09370
      RETURN                                                            SAR09380
      END                                                               SAR09390
      REAL FUNCTION SWIDTH(SL,VIS,ALT,WIND,CC)                          SAR09400
      X=ALOG(SL)                                                        SAR09410
      Y=ALOG(VIS)                                                       SAR09420
      IF(ALT.GE.200.)GO TO 1                                            SAR09430
      Z=ALT                                                             SAR09440
      GO TO 2                                                           SAR09450
    1 Z=ALT/1000.                                                       SAR09460
    2 XX=-3.34377+1.25887*X+2.55442*Y+0.01023*Z                         SAR09470
      XW=WIND/10.                                                       SAR09480
      F1=.886+XW*(.298-.116*XW)                                         SAR09490
      F2=1.131-CC*(-.472+.152*CC)                                       SAR09500
      SWIDTH=XX*F1*F2                                                   SAR09510
      RETURN                                                            SAR09520
      END                                                               SAR09530
      INTEGER FUNCTION JULIAN(XMO,N)                                    SAR09540
      DIMENSION C(12),J(12)                                             SAR09550
      DATA C(1),C(2),C(3),C(4),C(5),C(6),C(7),C(8),C(9),C(10),C(11),    SAR09560
     1C(12)/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG,3HSEP,3HOCT,SAR09570
     23HNOV,3HDEC/                                                      SAR09580
      DATA J(1),J(2),J(3),J(4),J(5),J(6),J(7),J(8),J(9),J(10),J(11),    SAR09590
     1J(12)/0,31,59,90,120,151,181,212,243,273,304,334/                 SAR09600
      DO 1 I=1,12                                                       SAR09610
      IF(C(I).EQ.XMO)GO TO 2                                            SAR09620
    1 CONTINUE                                                          SAR09630
      JULIAN =0                                                         SAR09640
      GO TO 3                                                           SAR09650
    2 JULIAN=J(I)+N                                                     SAR09660
    3 CONTINUE                                                          SAR09670
      RETURN                                                            SAR09680
      END                                                               SAR09690
```

```
C
C        PROGRAM TO EVALUATE OPTIMUM SIZES FOR SUCCESSIVE SQUARE
C                              SEARCHES
C
      DOUBLE PRECISION XX(400)
      DOUBLE PRECISION PRO(400)
      DIMENSION XSP(400),YSP(400)
      DIMENSION ZSP(400)
      DOUBLE PRECISION D,P(400),X(400)
      DIMENSION SF(5)                                                   SOL00040
      DOUBLE PRECISION RADIUS,ORD,XXX,AREA,DAREA,SAREA,PI2,PI8,RPEP,ALPHSOL00050
     1A,RPRIME,PIQ,DPIQ,SDPIQ,CORR,RSQ,SQA,CIA,COSD                     SOL00060
      REAL LAB(5)
      REAL*8 TITLE(12)/96HDIS10432 - PROBABILITY DENSITIES BETWEEN SUCCE
     1SSIVE OPTIMUM SQUARE SEARCHES - J.H.DISCENZA
     2          /
      DATA LAB/4HINIT,4H1ST ,4H2ND ,4H3RD ,4H4TH /
C
C        EVALUATE BIVARIATE NORMAL PROBABILITY DISTRIBUTION
C        FOR SQUARE AREAS WITH RESPECT TO R, R=1/2 OF ONE SIDE
      PI2=DSQRT(3.1415926536*2.0D0)                                     SOL00070
      PI8=8.0D0/PI2                                                     SOL00080
      PIQ=3.1415926536/4.0D0                                            SOL00090
      DPIQ=PIQ/45.0D0                                                   SOL00100
      SDPIQ=DSIN(DPIQ)                                                  SOL00110
      CORR=PI8*SDPIQ*0.01D0                                             SOL00120
      ITYPE=1                                                           SOL00130
      RADIUS=0.0D0                                                      SOL00140
      AREA=0.0D0                                                        SOL00150
      DO 1 I=1,400
      RADIUS=RADIUS+0.01D0                                              SOL00170
      ALPHA=DPIQ/2.0D0                                                  SOL00180
      DAREA=0.D0                                                        SOL00190
      DO 5 K=1,45                                                       SOL00200
      COSD=DCOS(ALPHA)                                                  SOL00210
      RPRIME=RADIUS/COSD                                                SOL00220
      CALL NPCA(RPRIME,ITYPE,ORD,XXX,ERR)                               SOL00230
      IF(ERR)14,9,14                                                    SOL00240
    9 ALPHA=ALPHA+DPIQ                                                  SOL00250
    5 DAREA=DAREA+ORD*RPRIME/COSD                                       SOL00260
      IF(I.EQ.1)GO TO 50                                                SOL00270
      PRO(I)=PRO(I-1)+DAREA*CORR
      GO TO 51                                                          SOL00290
   50 PRO(I)=DAREA*CORR
C
C        FIND DENSITY FUNCTION XX
   51 XX(I)=DAREA*CORR/(.08*RADIUS)
    1 CONTINUE                                                          SOL00320
```

```
      GO TO 6                                                           SOLC0330
   14 WRITE(6,22)I,RADIUS
    6 CONTINUE                                                          SOLC0350
      DO 40 I=1,400
   40 XSP(I)=FLOAT(I)/100.
      W=0.0
      WRITE(6,100)                                                      SOLC0410
      SF(1)=1.1                                                         SOLC0360
      SF(2)=1.6                                                         SOLC0370
      SF(3)=2.0                                                         SOLC0380
      SF(4)=2.3                                                         SOLC0390
      SF(5)=2.5                                                         SOLC0400
      DO 99 IIQ=1,2
C         SET SWEEP WIDTH
      W=W+0.05
      WPER=W/1.18
      IF(IIQ.GT.1)WRITE(6,106)
      WRITE(6,103)WPER
      DO 99 IQ=1,2
      IF(IQ.EQ.2)WRITE(6,105)
      DO 42 I=1,400
      X(I)=XX(I)
   42 P(I)=PRC(I)
      DO 99 II=1,5                                                      SOLC0420
      DO 41 I=1,400
      ZSP(I)=P(I)
   41 YSP(I)=X(I)
      MN=2
      IF(II.EQ.1)MN=1
      IF(II.EQ.5)MN=3
C
C         USING SAFETY FACTOR FIND LENGTH, EFFORT
      SIZE=SF(II)*1.18                                                  SOLC0430
      XL=4.*SIZE*SIZE/(FLOAT(IQ)*W)
      XLER=XL/1.18
      EFFORT=WPER*XLER
      WRITE(6,104)XLER,EFFORT
C         C
C         FIND PROBABILITY OF SUCCESS FOR THIS SEARCH AREA
      DSTAN=POD(W*XL/(4.*SIZE*SIZE))
      D=0.010D0                                                         SOLC0460
      J=SIZE*100.
      IF(J.GT.400)J=400
      POLD=P(J)*PCD(W*XL/(4.*SIZE*SIZE))
      SIZE=SIZE+.01                                                     SOLC0480
      PSTAN=POLD                                                        SOLC0490
      J=SIZE*100.
      IF(J.GT.400)J=400
```

```
C
C         FIND SIZE WHICH MAXIMIZES PROBABILITY OF SUCCESS, PMAX
      PR=  P(J)*PCD(W*XL/(4.*SIZE*SIZE))
      IF(PR-PCLD)11,2,3                                                 SOL00510
   11 D=-.01000                                                         SOL00520
      SIZE=SIZE-.01                                                     SOL00530
      GO TO 4                                                           SOL00540
    3 POLD=PR                                                           SOL00550
    4 SIZE=SIZE+D                                                       SOL00570
    7 J=SIZE*100.
      IF(J.GT.400)J=400
      PR=  P(J)*PCD(W*XL/(4.*SIZE*SIZE))
      IF(PR-PCLD)15,2,16                                                SOL00590
   15 PMAX=POLD                                                         SOL00600
      GO TO 2                                                           SOL00610
   16 POLD=PR                                                           SOL00620
      SIZE=SIZE+D                                                       SOL00630
      GO TO 7                                                           SOL00640
    2 I=SIZE*100.
      B=            PCD(W*XL/(4.*SIZE*SIZE))
      K=SF(II)*118.
      S1=FLOAT(IQ)*W/1.18
      SAZE=SIZE/1.18
      S=4.*SAZE*SAZE/XL
      WRITE(6,101)II,SAZE,S,P(I),B,PMAX,SF(II),S1,P(K),DSTAN,PSTAN
      IF(II.EQ.5)GO TO 99                                               SOL00710
C
C          FIND BAYES MULTIPLIER FOR PROBABILITIES INSIDE SEARCH AREA
      BAYIN=(1.-B)/(1.-PMAX)
C
C          FIND BAYES MULTIPLIER FOR PROBABILITIES OUTSIDE SEARCH AREA
      BAYOUT=1./(1.-PMAX)
C
C         USING BAYES' LAW, REEVALUATE DENSITY FUNCTION AND
C         PROBABILITY DISTRIBUTION
      DO 10 J=1,400
      IF(J-I)30,31,32
   30 P(J)=P(J)*BAYIN
      X(J)=X(J)*BAYIN
      GO TO 10
   31 PBACK=P(J)
      P(J)=P(J)*BAYIN
      X(J)=X(J)*BAYIN
      GO TO 10
   32 P(J)=P(I)+BAYOUT*(P(J)-PBACK)
      X(J)=X(J)*BAYOUT
   10 CONTINUE
   99 CONTINUE                                                          SOL00780
```

```
100 FORMAT('1',25X,'EXAMINATION OF CRITERIA FOR REPEATED SEARCHES'/// SOL00790
   116X,'INVERSE CUBE LAW, PARALLEL SWEEPS FOR PROBABILITY OF DETECTIOSOL00800
   2N'//35X,'LT J. H. DISCENZA, USCG'///'  SEARCH  OPTIMUM   TRACK    SOL00810
   3 PROBABILITY     PROBABILITY  PROBABILITY  STANDARD   TRACK',3('   SOL00820
   4 PROBABILITY')/'  NUMBER   RADIUS   SPACING  TARGET IN AREA  OF DETSOL00830
   5ECTION OF SUCCESS     RADIUS    SPACING   TARGET IN AREA  OF DETECTIOSOL00840
   6N    OF SUCCESS'///)                                                SOL00850
105 FORMAT(////9X,'REDUCE EFFORT 50% '///'  SEARCH  OPTIMUM   TRACK    SOL00810
   3 PROBABILITY     PROBABILITY  PROBABILITY  STANDARD   TRACK',3('   SOL00820
   4 PROBABILITY')/'  NUMBER   RADIUS   SPACING  TARGET IN AREA  OF DETSOL00830
   5ECTION OF SUCCESS     RADIUS    SPACING   TARGET IN AREA  OF DETECTIOSOL00840
   6N    OF SUCCESS'///)
101 FORMAT(I5,F11.2,F3.2,F11.3,F16.3,F13.3,F11.2,F9.2,F12.3,2F15.3/)    SOL00860
102 FORMAT('1',25X,'PROBABILITY DENSITIES'////)
 22 FORMAT('1'//' ***ERROR***'/////3I5,F20.2)                           SOL00870
103 FORMAT('0'///25X,'SWEEP WIDTH SET TO',F5.2,' TIMES PROBABLE ERROR'
   1//)
104 FORMAT(15X,'MILES FLOWN/PROBABLE ERROR=',F5.1,',  TOTAL EFFORT (W
   1X MILES FLOWN/PROBABLE ERROR) =',F5.1/)
106 FORMAT(1H1)
    STOP                                                                SOL00880
    END                                                                 SOL00890
    REAL FUNCTION POD(WS)
    DOUBLE PRECISION GG
    GG=.707106781*DSQRT(2.0D0*3.1415926536)*WS/2.0D0
    ORD=1.12837917*DEXP(-(GG*GG))
    GG=1.0/(1.0+0.3275911*GG)
    GG=1.0-((((0.94064607*GG-1.28782245)*GG+1.25969513)
   1*GG-0.252128668)*GG+0.225836846)*GG*ORD
    POD=GG
    RETURN
    END
C   ....................................................................SOL01110
C                                                                       SOL01120
C  A. IDENTIFICATION                                                    SOL01130
C     TITLE:  NORMAL PROBABILITY FUNCTION                               SOL01140
C     SHARE IDENTIFICATION:  C3 UCSD NPOA  (FORTRAN IV)                 SOL01150
C     PROGRAMMER:  P. G. SINGLETON, NORTH AMERICAN AVIATION, INC.,      SOL01160
C                  LOS ANGELES, DEPT. 056-072.                          SOL01170
C                  TESTED BY B. D. OLSON, UCSD.                         SOL01180
C                  CONVERTED TO FORTRAN IV BY JEAN ROW, FEBRUARY, 1967. SOL01190
C     DATE:  NOVEMBER, 1961.                                            SOL01200
C  B. PURPOSE:                                                          SOL01210
C     TO COMPUTE THE ORDINATE (DERIVATIVE) AND/OR AREA OF EITHER OF THE SOL01220
C     FOLLOWING PROBABILITY FUNCTIONS:                                  SOL01230
C     F(X)=1./SQRT(2.*PI)*I(EXP(-ALPHA**2/2.)D(ALPHA)                   SOL01240
C     WHERE "I(*)D(A)" INDICATES THE DEFINITE INTEGRAL OF "*"           SOL01250
C     BETWEEN -ABS(X) AND +ABS(X).                                      SOL01260
```

```
C        AND PI=3.14159                                                 SOL01270
C                                                                       SOL01280
C        H(X)=2./SQRT(PI)*J(EXP(-BETA**2)D(BETA)                        SOL01290
C        WHERE "J(*)D(B)" INDICATES THE DEFINITE INTEGRAL OF "*"        SOL01300
C                                                                       SOL01310
C        THE AREA OF EITHER FUNCTION CAN BE OBTAINED IN FIVE DIFFERENT  SOL01320
C        FORMS                                                          SOL01330
C        OF AREAL SEGMENTS, NAMELY:                                     SOL01340
C        1. CENTRAL                                                     SOL01350
C        2. SEMI-CENTRAL                                                SOL01360
C        3. TWO-TAIL                                                    SOL01370
C        4. SINGLE-TAIL                                                 SOL01380
C        5. CUMULATIVE FROM MINUS INFINITY.                             SOL01390
C     C. USAGE:                                                         SOL01400
C        1. CALLING STATEMENT:                                          SOL01410
C              CALL NPOA(XARG,ITYPE,ORD,AREA,ERR)                       SOL01420
C        2. ARGUMENTS:                                                  SOL01430
C              XARG - ARGUMENT ON THE ABSCISSA. (REAL*8)                SOL01440
C                     FOR P(X) THE ARGUMENT MUST LIE:                   SOL01450
C                                      0 .LE. ABS(X) .LE. 13.268609SOL01460
C                     FOR H(X) THE ARGUMENT MUST LIE:                   SOL01470
C                                      0 .LE. ABS(X) .LE. 9.382323  SOL01480
C              ITYPE - SIGNED INTEGER VARIABLE WHICH SPECIFIES FUNCTION SOL01490
C                      TYPE AND FORM OF THE ORDINATE AND/OR AREA.       SOL01500
C                                                                       SOL01510
C             ITYPE       FORM                                          SOL01520
C           P(X) H(X)                                                   SOL01530
C             +1   -1   CENTRAL AREA FROM -X TO ABS(X)                  SOL01540
C             +2   -2   SEMICENTRAL AREA FROM ZERO TO ABS(X)            SOL01550
C             +3   -3   TWO-TAIL AREA BEYOND -ABS(X) AND +ABS(X)        SOL01560
C             +4   -4   SINGLE-TAIL AREA BEYOND ABS(X)                  SOL01570
C             +5   -5   AREA FROM MINUS INFINITY TO ABS(X)              SOL01580
C             +6   -6   ORDINATE VALUE ONLY                             SOL01590
C              ORD - ORDINATE ANSWER (REAL*8)                           SOL01600
C              AREA - AREA ANSWER (REAL*8)                              SOL01610
C              ERR - ERROR INDICATOR WHICH DENOTES RETURN FROM THE      SOL01620
C                    SUBROUTINE. (REAL)                                 SOL01630
C                    SUCESSFUL RETURN, ERR =  0.0                       SOL01640
C                    UNSUCCESSFUL RETURN, ERR = +1.0                    SOL01650
C                                         ERR = -1.0                    SOL01660
C        3. ERROR RETURNS:                                              SOL01670
C           IF THE ARGUMENT EXCEEDS THE LIMIT AS DEFINED IN C2, THE FOLLOWISOL01680
C           VALUES WILL RESULT:                                         SOL01690
C                                                                       SOL01700
C           ITYPE  AREAL SEGMENT                    ORD    AREA         SOL01710
C           -----  -------------                    ---    ----         SOL01720
C             1    CENTRAL AREA                      0     1.0          SOL01730
C             2    SEMICENTRAL AREA                  0     0.5          SOL01740
```

```
C             3    TWO-TAIL AREA                          0    0.0       SOL01750
C             4    SINGLE-TAUL AREA                       0    0.0       SOL01760
C             5    CUMULATIVE AREA FROM MINUS INFINITY    0    1.0       SOL01770
C             6    ORDINATE ONLY                          0    ---       SOL01780
C                                                                        SOL01790
C      4. ACCURACY:                                                      SOL01800
C           RELATIVE ERROR:                                              SOL01810
C              FOR ORDINATE - LESS THAN 3*10**-9                         SOL01820
C              FOR AREA     - LESS THAN 15*10**-8                        SOL01830
C      5. CAUTIONS:  SEE C2                                              SOL01840
C      6. REFERENCES:                                                    SOL01850
C         1. "IBM JOURNAL OF RESEARCH AND DEVELOPMENT", APRIL 1957,      SOL01860
C            VOLUME 1, NO.2, PP.110-115, E. G. KOGBETLIANTZ,             SOL01870
C            "COMPUTATION OF E**N USING ELECTRONIC COMPUTERS".           SOL01880
C         2. "APPROXIMATIONS FOR DIGITAL COMPUTERS", C. HASTINGS, JR.,   SOL01890
C            PRINCETON UNIVERSITY PRESS, 1955, P.169.                    SOL01900
C                                                                        SOL01910


      SUBROUTINE NPCA (XARG,ITYPE,ORD,AREA,ERR)                          SOL01920
      DOUBLE PRECISION XARG,ORD,AREA,RR                                  SOL01930
      IF (IABS (ITYPE)-6)7,7,16                                          SOL01940
7      RR=DABS(XARG)                                                     SOL01950
      AREA=0.0                                                           SOL01960
      IF(ITYPE)9,16,8                                                    SOL01970
8      RR=0.707106781* RR                                                SOL01980
9     KTYPE=IABS (ITYPE)                                                 SOL01990
      IF(( RR**2)-88.028)15,15,10                                        SOL02000
10    ORD=0.0                                                            SOL02010
      IF(IABS (ITYPE)-6)11,17,11                                         SOL02020
11    AREA=1.0                                                           SOL02030
      GO TO 19                                                           SOL02040
15    ORD=1.12837917*DEXP(-( RR**2))                                     SOL02050
      IF(IABS (ITYPE)-6)12,6,12                                          SOL02060
12    AREA=1.0/(1.0+0.3275911* RR)                                       SOL02070
      AREA=1.0-(((((0.94064607*AREA-1.287822453)*AREA+1.25969513)        SOL02080
     1*AREA-0.252128668)*AREA+0.225836846)*AREA*ORD                      SOL02090
19    GO TO(6,2,3,4,5),KTYPE                                             SOL02100
2     AREA=AREA/2.0                                                      SOL02110
      GO TO 6                                                            SOL02120
3     AREA=1.0-AREA                                                      SOL02130
      GO TO 6                                                            SOL02140
4     AREA=(1.0-AREA)/2.0                                                SOL02150
      GO TO 6                                                            SOL02160
5     AREA=(1.0+AREA)/2.0                                                SOL02170
6     IF(ITYPE)17,16,14                                                  SOL02180
```

```
16    ORD=0.3535533905*ORD                                                SOLC2190
17    ERR=0.0                                                             SOLC2200
      GO TO 19                                                            SOLC2210
16    ERR=1.0                                                             SOLC2220
18    RETURN                                                              SOLC2230
      END                                                                 SOLC2240
```

References

1. U. S. Coast Guard, National Search and Rescue Manual, (FM 20-150; NWP 37(A); AFM 64-2; CG-308), Amendment 1, 1 April 1968.

2. Navy Operations Evaluation Group Report No. 56, Search and Screening, Bernard O. Koopman, 1946.

3. Navy Weather Research Facility, Synoptic Analysis and Forecasting of Surface Currents, W. E. Hubert and T. Laevastu, June 1967.

4. Scripps Institution of Oceanography, SIO Ref. 68-30, Empirical Sweep Width Analysis, W. H. Richardson, October 1968.

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13. ABSTRACT

A computer program is presented which solves the search planning problem for survivors at sea. The program is designed to utilize weather data as compiled by the United States Navy at its Fleet Numerical Weather Central, Monterey, California.

An investigation is also made into the search criteria used by the United States Coast Guard in its planning procedures. Guidelines are given for the use of the square search and the Sector search.

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